The Need for Speed: The Importance of Next-Generation Broadband Networks

BY STEPHEN EZELL, ROBERT ATKINSON, DANIEL CASTRO AND GEORGE OU | MARCH 2009

Supporting the widespread deployment of next-generation broadband Internet will enable the emergence of a whole host of online applications and services, many of which we can barely imagine today, that will increase quality of life and boost economic growth.

Digital Equipment Corporation CEO Ken Olsen famously commented in 1977 that, "No one will ever want a computer in their home,"[1] setting off a long-standing trend in the history of information technology of underestimating consumer demand for faster computers with improved processing speeds, memory, and disk storage capacity. Repeatedly, increases in CPU processing speed, memory, and storage capacity have been met with new applications and programs leveraging that increased speed, memory, or capacity. This dynamic has also been equally true with regard to demand for faster transmission speeds across digital telecommunication networks. And just as even titans of the computing industry could not envision at the time the applications that would usher forth from dramatically faster computers with more storage capacity, so too can we only begin to envision the applications that next-generation broadband will make possible.

Indeed, facilitating the widespread deployment of next-generation broadband Internet—with download speeds of at least 20 megabits per second (Mbps), and ideally 50 Mbps or upwards, and upload speeds of 10 Mbps or greater[2]—will enable the emergence of a whole host of online applications and services, many of which we can barely imagine today. The true potential of this next-generation broadband network lies in the transformative new functionalities it enables. These functionalities—including faster file transfers, streaming data such as video, and real-time collaboration tools—will support a broad range of Web-based applications delivering tremendous benefits to consumers, educational institutions, businesses, society, and the economy.

Notwithstanding the importance of boosting broadband speeds, policymakers in the United States have largely focused to date on reducing the "digital divide" by increasing broadband availability to and adoption by most households and businesses. While ensuring that all Americans have access to the Internet and the capability to use it is a must, supporting the deployment of faster next-generation broadband networks will also be critical to applications and services that will play important roles in improving quality of life and boosting economic growth.

The true potential of the next-generation broadband network lies in the transformative new functionalities it enables and the innovative Web-based applications it supports.

This report lays out a vision of what the Internet could look like with the ubiquitous deployment of next-generation broadband service. Ubiquitous next-generation broadband access is defined as available to, but not necessarily adopted by, at least 90 percent of the population. Unlike others, this report does not define ubiquitous broadband as 100 percent coverage because, at least for the foreseeable future, the cost of connecting the most remote homes to next-generation networks would be prohibitively high.

In this report, fiber to the home (FTTH), fiber to the node (FTTN),[3] and DOCSIS 3.0 cable technology are considered next-generation fixed-line broadband deployments. With regard to next-generation wireless broadband, so-called 4G, or "fourth generation," wireless technologies, particularly WiMax and LTE (or "Long-Term Evolution"), are emerging, bringing very fast mobile Internet services. The leading edge of 4G rollouts has begun with WiMax deployments and will accelerate with Verizon LTE deployments in 2010, with mainstream technology rollouts and market adoption picking-up in 2011 and 2012. Next generation wireless technology such as LTE can under ideal conditions have the same capability as next-generation wired broadband technologies. In particular, 4G wireless can be a good alternative to fixed wireline in rural areas where subscriber density is low and fixed outdoor antennas are used to maximize radio signals.

Just as with speed, mobility—the ability to access Web-based resources at high-speeds from cell phones, PDAs, laptop computers, or other devices—will be vitally important in envisioning the future of the Internet. Though not explicitly the focus of this report, with sufficient bandwidth delivered over next-generation wireless networks, many of the applications discussed herein can work equally effectively whether accessed via the home computer connected to fixed-line broadband, or via a mobile device connected to the wireless network.

The American Recovery and Reinvestment Act allotted $7.2 billion to support broadband. Given the relatively limited funds allocated to broadband in the stimulus package, we believe that the most effective use of these funds is to support the deployment of moderate speed broadband to homes or businesses in unserved areas, and not be used to subsidize higher speeds in areas where homes can already subscribe to broadband. We suggest moderate, as opposed to high speeds, since there is normally a tradeoff of coverage extent versus speed. We suggest a focus of stimulus funds on unserved areas because the cost of connecting unconnected homes and businesses is greater than the funds available, and this is an important opportunity to bring connectivity to these areas.

However, beyond the stimulus public policy needs to also focus on supporting faster broadband speeds for all Americans. Due to the positive network externalities that next-generation broadband Internet access bestows, proactive policy intervention is justified not just to extend broadband service to the Americans who lack it, but also to investments in networks, or parts of networks (e.g. fiber extensions), that support higher speeds. While it is beyond the scope of this report to lay out a detailed policy agenda for increasing broadband speeds, there are at least three key recommendations to consider:

- First, extend financial incentives, such as accelerated depreciation or tax credits, for investments by broadband providers in faster networks. Such incentives should be focused on investments that support higher speeds, but should be done to the extent possible in ways that do not distort competition.

- Second, communities seeking faster networks should if possible embrace public-private private partnerships with existing providers and not subsidize expensive "overbuilding" projects when there is already an existing network in the community that can in almost all cases be upgraded to faster speeds more cheaply than building an entirely new network. In this sense it is far more cost effective to work with those providers to expand coverage than to subsidize a redundant third (or fourth) *pipe* to a community.

- Third, policymakers should continue to make adequate spectrum available to support next-generation wireless innovation.

THE INTERNATIONAL CONTEXT

While different studies have reported slightly different numbers—one August 2008 study found median U.S. broadband speeds to be 2.3 Mbps downstream and 0.435 Kbps upstream,[4] while another found the average U.S. broadband speed at year-end 2007 to be 4.9 Mbps downstream[5]—it seems fair to conclude that median U.S. broadband speeds are less than 5 Mbps. While the speeds considered optimal in this report—20 to 50 Mbps downstream and at least 10 Mbps upstream—may seem ambitious given that median U.S. broadband speeds are currently less than 5 Mbps, they are certainly realistic compared to the median download speeds already achieved in nations such as Japan (63 Mbps) and South Korea (49 Mbps).[6]

In fact, today nearly all Japanese citizens have access to next-generation broadband, with median connection speeds over fifteen times faster than the United States.[7] South Korea, a country with 1/6th the population of the United States, has almost as much Internet traffic as all of North America.[8] And South Korea is not satisfied with its current speeds; the Korean Communications Commission announced on February 2, 2009 an initiative to widely deploy 1 gigabit per second (e.g. 1,000 Mbps) broadband—both upstream and downstream, that is, "symmetrically"—by 2012.[9] Even China has announced plans to build its first nationwide high-capacity fiber optic network, which would allow most users 100 megabit per second access.[10]

As documented throughout this report, the already-deployed next-generation broadband networks in countries such as Japan, Singapore, South Korea, and Sweden are making possible innovative Web-based applications and services in business management, business models, research applications, telecommuting, telemedicine, public safety, education, and entertainment that are simply not possible in many areas of the United States that lack next-generation broadband networks. This is cause for concern.

The United States, like most other countries, is behind the technology possibility frontier in deploying next-generation broadband networks.

Vinton Cerf, one of the Internet's chief architects, contends that, "Japan's lead is worrisome because it will shift Internet innovation away from the United States." And as author Thomas Bleha argued in *Foreign Affairs* magazine, "By dislodging the United States from the lead it commanded [in broadband] not so long ago, Japan and its neighbors have positioned themselves to be the first states to reap the benefits of the broadband era: economic growth, increased productivity, technological innovation, and an improved quality of life."[11] Bleha continues:

> Asians will have the first crack at developing the new commercial applications, products, services, and content of the high-speed broadband era. These will include not only Internet telephones and videophones, but also easy teleconferencing, practical telecommuting, remote diagnosis and medical services, interactive distance education, rich multimedia entertainment, digitally-controlled home appliances, and much more.[12]

To be sure, the United States has made some progress in next-generation broadband deployment. While most U.S. cable broadband providers offer 3-15 Mbps downstream service and most DSL broadband providers offer 0.75-6 Mbps downstream service, higher-speed broadband is increasingly coming on the scene. By the end of 2008, Verizon's FiOS fiber to the home service garnered approximately 2.5 million broadband subscribers out of 10 million homes with access to the service.[13] AT&T's fiber to the node service, U-verse, had one million subscribers by December 2008, out of 17 million homes with access to the service, with a goal of reaching 30 million by 2011. And cable companies such as Comcast had begun to roll out next-generation DOCSIS 3.0 services, with 10 million homes having access to this service by the end of 2008. Comcast expects to reach approximately 30 million homes with DOCSIS 3.0 service by the end of 2009.[14] In total, about one quarter of U.S. households had access to next-generation broadband service by year-end 2008.[15]

Even though the United States is behind such densely populated nations like Japan and South Korea, it is the only country where fiber is being deployed in largely suburban areas with single family homes.[16] And as ITIF documented in "The Atlantic Century: Benchmarking EU and U.S. Competitiveness," the United States leads the European Union-15 region as a whole in broadband speed and subscribership, although it still trails its leading European peers, including Sweden, France, and the United Kingdom—not to mention the Asian leaders.[17]

Regardless of where the precise U.S. rank lies, what matters is that the United States, like many countries, is considerably behind the technology possibility frontier.[18] In general, most countries need to be much more focused on catching up to the technology frontier and making technological innovations in broadband speeds a reality for their citizens.

The race is on for global broadband leadership. Communities that lack high-speed broadband Internet access are at a deficit in comparison to their peers: research has shown that communities with broadband access grow faster than communities without it.[19] In a like manner at the national level, relatively slow broadband speed in the United States, especially compared to some Asian nations, places it at a disadvantage compared to peer countries.

THE SHIFT TO AND NEED FOR NEXT-GENERATION BROADBAND NETWORKS

The history of networking computers—as with the microprocessors that run them—has been characterized by increasing speeds and decreasing costs. The first commercially-available modem for computers, the Bell 103 modem, operated at 300 bits per second in 1964. Modem speeds rose to 2,400 bits per second by 1989, and grew to about 28.8 Kbps in 1995.[20] But still by the late 1990s, most Americans accessed the Internet via 56 Kbps dial-up service, and few had access to broadband. In fact, at the beginning of this decade, only 4.5 percent of U.S. households had broadband access.[21]

But a paradigm shift occurred during the beginning to middle of this decade, as users increasingly adopted broadband at speeds of up to 1.5 Mbps. Critically, this paradigm shift resulted not merely from moving to an "always-on" environment, rather it arose because broadband enabled a wealth of services and applications that simply were not practical at the lower speeds, such as blogging, e-commerce, social networking, discovering health information, podcasting, distance education, voice over Internet Protocol (VoIP), and many others. Thus, the jump to broadband speeds represented an inflection point making possible a myriad of services that were previously impractical.

That the United States is not at the world's vanguard in deploying next-generation broadband is disappoint-

BOX 1: WHAT IS BANDWIDTH?

Bandwidth is a basic measure of performance for computer networks, including Internet broadband service. It determines the rate (throughput) at which computer data moves through a network, and thus how quickly files can be transferred over a network. Bandwidth measures the throughput of sending data (upload) and receiving data (download). The basic unit used to describe bandwidth is bits per second (bps) but prefixes such as K (kilo - thousand), M (mega - million), or G (giga - billion) are appended in front of the unit. For example, a 5 Mbps broadband connection is able to transfer 5 million bits in a single second.

Bandwidth is sometimes casually, but incorrectly, referred to as "speed." Ultimately, all bits on an electronic network travel at the same speed (the speed of light). Thus, it is the size, the bandwidth capacity, of the broadband network that really matters.

TABLE 1: BANDWIDTH REQUIREMENTS FOR BROADBAND APPLICATIONS

Application	Upstream Speed	Downstream Speed
Medium-Resolution Videoconferencing (640x480P)	384-1200 Kbps	384-1200 Kbps
Streaming Video (720P)		1.2 - Mbps
Standard-Definition Digital Television (720x480 Interlaced)		4 Mbps
Basic HD Videoconferencing (1280x720 resolution)	1.2 - 4 Mbps	1.2 - 4 Mbps
Telepresence: High-Resolution HD Videoconferencing (1920x1080 resolution)	5 Mbps	5 Mbps
Video Home Security Service	10 Mbps	
High-Definition (HD) Digital Television (1440x1080 Interlaced)		15 Mbps
Telepresence: Very High-Resolution HD Videoconferencing (5760x1080)	15 Mbps	15 Mbps

ing, because just as the migration from dial-up Internet to first-generation broadband represented a paradigm shift that opened up a new world of Web applications, so will the transition to next-generation broadband unleash a new wave of innovation.

What Makes Next-Generation Broadband Different

Next-generation broadband enables several transformative functionalities that support the development of more compelling, powerful, and useful Web-based applications capable of delivering substantial benefits to consumers, society, academic institutions, businesses, and the economy. The four main functionalities are: 1) dramatically faster file transfer speeds for both uploads and downloads; 2) the ability to transmit streaming video, transforming the Internet into a far more visual medium; 3) the means to engage in true real-time collaboration; and 4) the ability to use many applications simultaneously.

1) Next-generation broadband will enable faster file transfers, dramatically improving a consumer's experience with sending and receiving data, pictures, and audio and video files over the Internet. Faster file transfers also make practical the realization of "cloud computing," a vision of computing where computer programs and applications, content, and file storage no longer need to reside primarily on a user's desktop computer, but can be stored on remotely-located servers. Cloud computing holds the power to revolutionize how consumers interact with their computing platforms.

However, a key attribute of next-generation broadband is not just its faster download speeds, but also its much faster upload speeds, making it much easier for consumers to upload content, such as user-generated videos, to the Internet. As Mark Pontarelli, a General Manager for Intel's New Business Initiatives team, explains:

> The faster upstream speeds that next-generation broadband makes possible will allow users to create knowledge at the edge of the network, and inject it back into the core of the network, leveraging the many-to-many aspect of high-speed broadband networks. Empowering end-users with the bandwidth needed to create, package, and broadcast their knowledge, skills, and creative talents will unlock untold innovation potential. Websites will appear that let citizens sell instructional or training videos on any topic in which they have special interest, knowledge, or expertise, from cooking, to home remodeling, to using software programs.[22]

A good example of this "outside-in" business model is the firm Global Scholar, called "the world's most ambitious education portal," which has built an infrastructure that allows over 1,500 registered tutors to create and sell their own coaching videos for English, science, math, languages, economics, and SAT and ACT exams.[23] South Korean firm Megastudy has used a similar model enabled by high-speed broadband to transform South Korea's test preparation market, turning the teachers who produce the best instructional videos for preparing for the grueling national aptitude test into national celebrities.[24]

2) Next-generation broadband will enable video streaming applications. By making high-quality video on demand (VoD) possible at a technical level, next-generation broadband will lead to a revolution in video distribution. American consumers with next-generation

FIGURE 1: A DESKTOP VIDEOCONFERENCING DEVICE

broadband would be able to download full-length feature films in minutes, just as consumers in Japan and South Korea do today. This functionality also facilitates higher-quality video streaming from services such as YouTube, Hulu, ABC, CNN, Netflix, and many others. It also makes practical Internet Protocol Television (IPTV), in which television service is delivered interactively to the home through the broadband connection. With these technology advancements, consumers will no longer be limited by the notion of a fixed television schedule or a limited number of channels.

Next-generation broadband will be required to support concurrent usage of high-bandwidth consuming applications, such as videoconferencing, telepresence, IPTV, and high-definition and ultra-high-definition television (HDTV and UHDV). (Table 1).

3) Next-generation broadband enables high-quality real-time collaboration. Videoconferencing applications, whether using a Web camera connected to a VoIP call or a more sophisticated desktop videoconferencing device (Figure 1), will add two-way video to the old-fashioned phone call. Advanced videoconferencing systems, often called "telepresence" (Figure 2), reproduce an immersive, in-person experience that makes participants feel they are literally in the same room together, giving a new meaning to "face-to-face communications." Videoconferencing and telepresence applications provide the ability to connect to anyone in the world and work as if all participants are in the same location, together solving problems and interacting in such an immediate and information-rich manner that it is no longer simply an interaction but a collaboration in real-time.[25]

Video-based telepresence systems will soon connect businesses, schools, hospitals, homes, and public agencies. By reducing geographic boundaries, businesses will become more competitive through enhanced collaboration. Access to the best teachers, professors, and medical specialists in the world will no longer be dictated by location. Engineers, software developers, and marketing specialists will be able to collaborate with each other as if they were face to face. But all of this will only become possible if the fidelity of the sound and sight are of high enough quality—demanding sufficient bandwidth (and the management of that bandwidth)—and if the technology becomes as ubiquitous as the telephone.

4) Next-generation broadband enables users to run a multiplicity of bandwidth-hungry applications simultaneously. It is the aggregation of these bandwidth-hungry applications—in addition to any single application's bandwidth requirement—that especially drives the need to deploy ubiquitous next-generation broadband. Moreover, the homes of today, unlike the analog homes of the past, may have up to thirty different electronic devices, almost all of which can communicate with one another and the network. This multitude of electronic devices—digital cameras, home video editing equipment, cell phones, PDAs, digital

FIGURE 2: A MEETING VIA PERSONAL TELEPRESENCE

TABLE 2: DIFFERENCES BETWEEN TODAY'S AND THE NEXT-GENERATION INTERNET

Today's Internet	Next-Generation Internet
Independent: downloading music from all over the world	Collaborative: Creating music with other musicians all over the world
Reactive: websites	Interactive: virtual worlds
Private resources: online backups	Shared resources: online file servers and remote devices
Centralized computing: local data sets and computing	Cloud computing: distributed data sets and computing
One-to-one or one-to-many communication: webcam chats	Many-to-many communication: virtual conferences
Low quality: lower quality audio and video	High quality: high-definition audio and video

video recorders, HDTVs, laptop computers, home monitoring systems, smart appliances, etc.—increases demand for broadband, as these devices allow individuals to both consume and produce content and give them the means to share it with others.

It is not a stretch to envision a household of the near-future having at least the following demands for high-speed broadband Internet access: Mom engaged in a videoconference for her home-based business; dad watching a live HDTV football game; daughter using the computer to access streaming video of a college course lecture; son playing a real-time interactive game; relatives, perhaps grandparents, in town with one downloading an episode of a high-definition movie and another connected to an uninterruptable medical video feed to a remote monitoring facility. In the background, home appliances are being monitored and video home security devices are sending video feeds back to the to the home security company's emergency operations management center.[26] This home would easily consume more than 90 Mbps of aggregate bandwidth (both directions): 15 Mbps per HDTV stream x 2 HDTV streams, 80 Kbps for gaming, 18 Mbps for high-definition two-way video conferencing (requiring 18 Mbps both upstream and downstream), 15 Mbps for a video course lecture, and 10 Mbps for home security and home-based monitoring uses.[27]

Taken together, these four transformative functionalities enabled by next-generation broadband mean that the key characteristics of services and applications running on the next-generation Internet will look very different from those running on today's network, as Table 2 summarizes.

And while the broadband applications referenced above are only the ones we can imagine today, Internet architect Cerf recognizes this is just the beginning, noting that, "Once you have very high speeds, I guarantee that people will figure out things to do with it that they haven't done before."[28] Indeed, the history of information technology has been that people rapidly find new uses for additional memory, storage, processing speeds, and transmission speeds and there seems to be no end in sight.

We now turn to the specific benefits that next-generation broadband will bring to consumers, society, educational institutions, and businesses. Table 3 (following page) provides a list of the applications enabled (or made more effective) by next-generation broadband.

BENEFITS OF NEXT-GENERATION BROADBAND TO CONSUMERS

Faster broadband enables faster file transfers

Faster broadband enables faster file transfers, dramatically improving consumers' online experience and supporting new or expanded services, such as geographic information systems or satellite image mapping. Faster broadband means that a file that takes 60 minutes to download on a typical 3 Mbps broadband connection only takes 3.6 minutes on a 50 Mbps broadband connection. Faster speeds will make it easy to download large files like medical images, digital photographs, movies, maps, and much more. For example, a typical digital camera produces an 8 megabyte (MB) uncompressed raw image, which takes 21 seconds to download on a 3 Mbps broadband connection. On such a connection, to download 100 pictures taken on the family vacation would take over 35 minutes. While it is true that compression techniques can be employed to shrink the images down to 1 MB, a substantial amount of image quality gets lost in that process, meaning that consumers do not get the most from their cameras because of slow broadband. Another aspect of faster broadband is faster uploads, which is just as important as faster downloads. It takes 147 seconds to upload an 8MB image at today's typical upload speed of 0.435 Mbps. Transmitting that same image over next-generation broadband operating at 10 Mbps upstream would take only 6.4 seconds.

It is the aggregation of these bandwidth-hungry applications—in addition to any single application's bandwidth requirement—that especially drives the need to deploy ubiquitous next-generation broadband.

More importantly, when consumers want to upload videos, conventional broadband services are not up to the task because they take several hours just to upload 10 minutes of high-definition (HD) video. With artists and consumers alike purchasing HD video cameras for as little as $130, they want to be able to quickly upload these movies to services such as YouTube to share their HD video with the world. The problem is that just 10 minutes of video footage from one of these HD video cameras consumes 900 megabytes. This means that on a conventional broadband connection with 0.435 Mbps upstream bandwidth, a 10 minute video clip takes a grueling 4.5 hours to upload to the server, making individuals much less inclined to contribute content. But with next-generation broadband services offering 10 Mbps of upload bandwidth, that same 10 minute video clip can be uploaded in just 12 minutes.

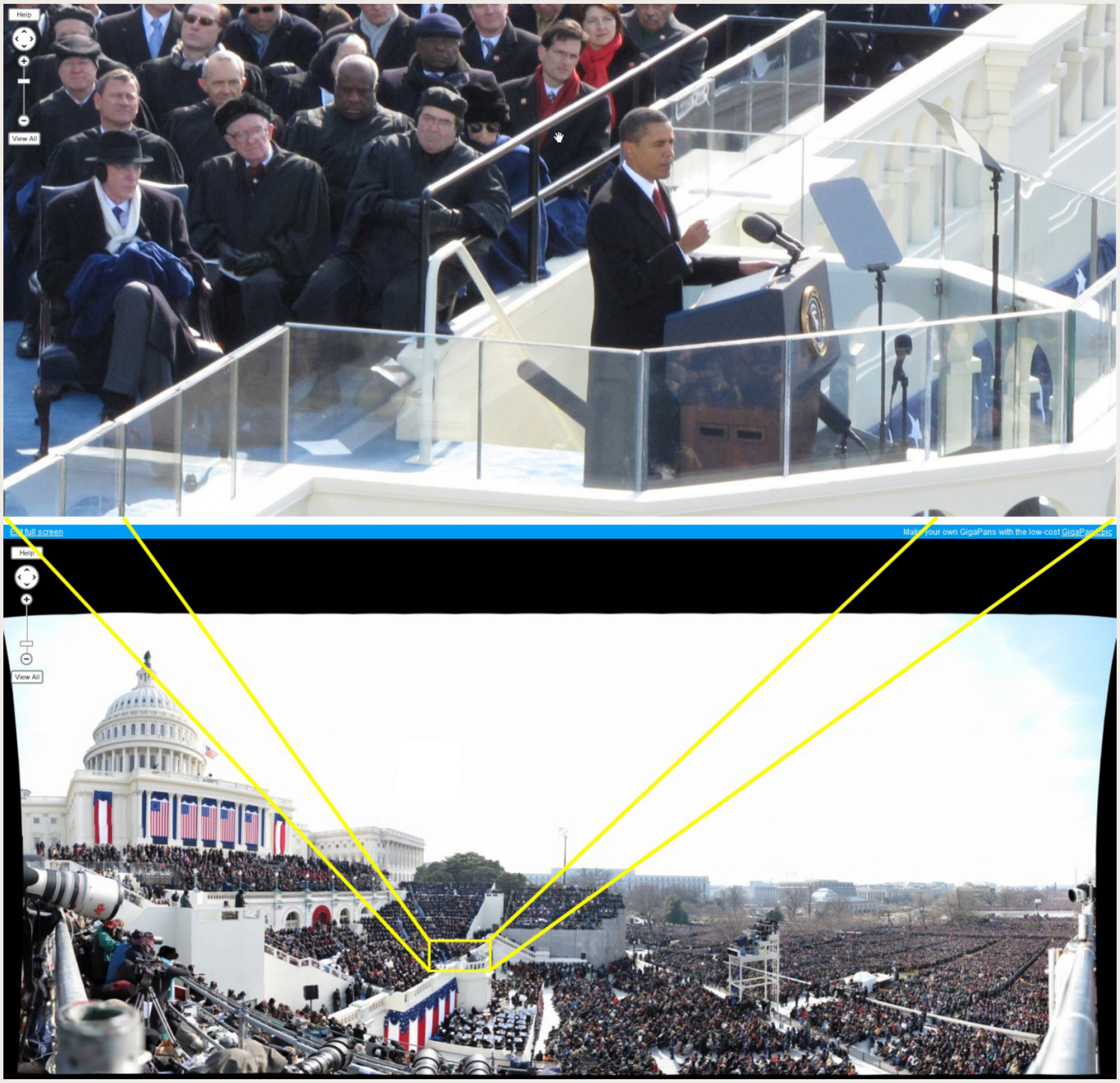
With current-generation broadband, the highest quality video rentals or sales can only realistically be delivered through physical media and transportation (hence Netflix and Blockbuster). Using a typical 3 Mbps Internet connection would take up to 36 hours to download a 50 gigabyte (GB) Blu-ray movie; an 8 GB DVD would take over 4 hours to download, which is still unattractive to use. With next-generation broadband operating at 50 Mbps downstream, a feature-length movie can be delivered in less than 15 minutes, and a Blu-ray movie can be delivered in less than 2.5 hours.

TABLE 3: NEXT-GENERATION BROADBAND-ENABLED APPLICATIONS

Consumer and Business	Videoconferencing
	IPTV (Internet Protocol Television)
	High-Definition Video Streaming
	Ultra High-Definition Video Streaming
	Video on Demand
	Place-Shifted Video
	Cloud Computing
	Online and Cloud-based Gaming
	Smart Homes, Buildings, and Appliances
	Sharing High-Resolution Digital Images
	Remote Computer Aided Design (CAD)
	3D Graphics Rendering Server Farms
	Remote Network Management/Managed Services
	Virtual Collaboration Spaces
Society	Virtual Sports (Sports at a Distance)
	Intelligent Transportation Applications
	First Responder Networks
	Emergency Dispatch and Coordination
	Webcast Agency Meetings (e.g. Congressional Hearings)
Health Care	Teleconsultations
	Telepathology
	Telesurgery
	Remote Patient Monitoring
	Remote Diagnosis
	Remote Medical Imaging
	Grid Computing for Medical Research
Education and Research	Distance Education
	Virtual Classrooms/Rehearsals
	Remote Instrumentation
	Multi-Campus Collaboration
	Digital Content Repositories and Distribution
	Data Visualization
	Virtual Laboratories
	Grid Computing in Academic Research

This is already old hat in Japan and South Korea, where it's common for consumers to download feature-length movies to personal computers in minutes. Some South Korean consumers even have access to 10 to 30 Mbps mobile WiMAX service, meaning some can download feature-length movies to their cell phones faster than most Americans can download them to their computers.

FIGURE 3: A GIGAPAN IMAGE OF PRESIDENT OBAMA'S INAUGURATION[29]



The faster file transfers next-generation broadband enables also make it possible to view much finer resolution and detail in maps and images. For example, Gigapan.org is a website that allows ordinary consumers using cheap digital cameras to create and upload multi-gigapixel images that can be gigabytes (billions of bytes) in size. Website visitors are able to view these images and zoom in and out of them. Figure 3 illustrates a Gigapan image taken at President Obama's inauguration, showing the incredible detail visible when zooming in on the original image.

Gigapan Systems sells a $379 robotic panning system (shown in Figure 4) that holds a consumer-grade digital camera and automatically takes Gigapan photos. The system then takes tens to hundreds of images and stitches them together. A Gigapan photo that is 10 photos tall and 18 photos wide using 8 megapixel images would produce a single image out of 180 different images. Such a photo would contain approximately 1.2 billion pixels (requiring 9.6 billion raw bits to store), but could be compressed to roughly 150 megabytes. Downloading the image would take nearly 7 minutes

FIGURE 4: GIGAPAN ROBOTIC CAMERA PANNING SYSTEM

on a 3 Mbps broadband connection (or it would require users to wait 10 seconds at a time to progressively download the image one piece at a time as they pan and zoom in on the image). While this scheme works slowly with today's connections, the interface would behave instantaneously on next-generation broadband.

Google Maps (Figure 5) also uses a similar approach to deliver satellite imagery of the earth to consumers. Because there are potentially thousands of trillions of bytes of satellite image data to cover every square inch of land mass, the map server only delivers a tiny portion of that data to the user for the parts of the Earth the user is looking at. Each time the screen is zoomed or panned, additional data has to be downloaded and this can be sluggish on today's sub-5 Mbps broadband networks. This makes many Google Maps users resort to the plain version of Google Maps which does not contain actual satellite imagery but rather simple drawings. Next-generation broadband would make the higher-quality satellite image service more responsive and therefore more attractive.

Microsoft's Photosynth[30] (Figure 6) is one of the most compelling blends of 3D and digital imaging applications to date. It allows users to string any number of images together into a virtual 3D world that people can explore without requiring a robotic panning device or fixed camera position. This adds three-dimensional spatial awareness to two-dimensional photographs. From a bandwidth requirement perspective, this application is similar to Gigapan images and satellite image mapping—it needs more bandwidth to offer higher image quality and more instantaneous response times.

Google Maps, Gigapan, and Photosynth are three very useful applications whose appearance or utility would have been impossible to predict. They would never have emerged without broadband, they perform better with faster broadband, and they point to the kind of exciting new applications that will become possible once next-generation broadband is ubiquitously deployed.

FIGURE 5: GOOGLE MAPS

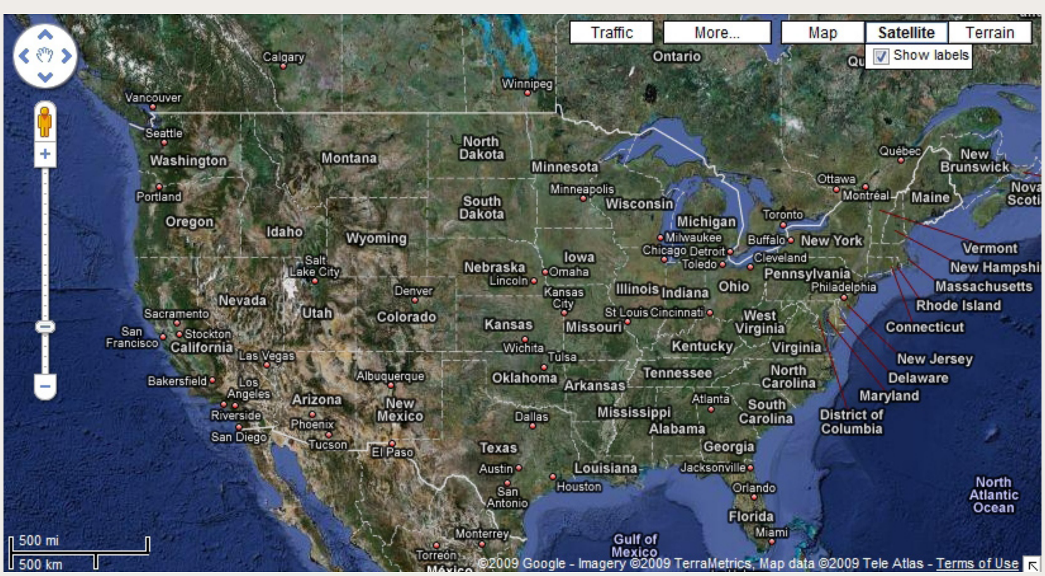
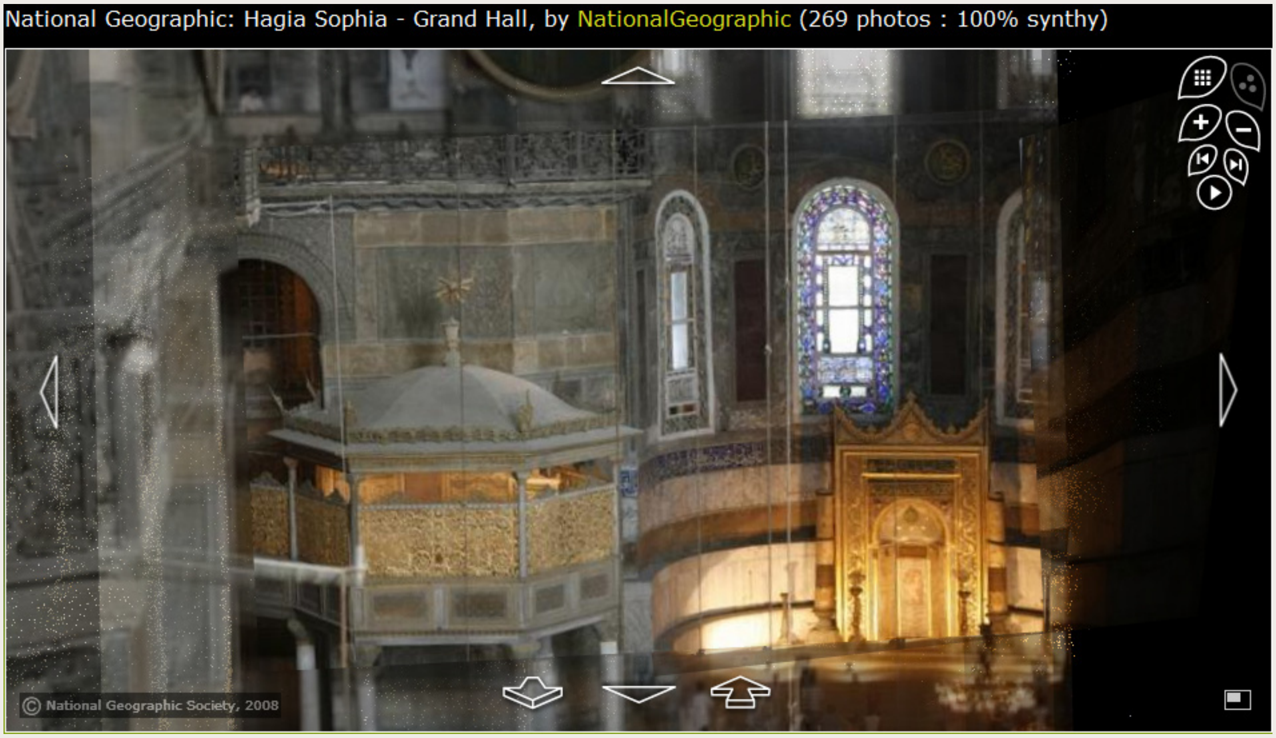


FIGURE 6: A PHOTOSYNTH IMAGE



Faster broadband enables video streaming applications

Faster broadband allows video streaming applications that require high levels of fixed bandwidth to work. Unlike file transfer applications, video streaming applications do not grow to fill available network capacity, but they have to receive a minimum amount of bandwidth, or they often will not work at all.

A good example of an application enabled by next-generation broadband is Internet Protocol Television (IPTV)—television delivered to the home, particularly to high-definition television sets, over the broadband Internet connection—which requires a perfectly consistent minimal bitrate of 8 Mbps to support high-definition video. IPTV is the telephone company's alternative to the cable (or satellite) TV company's subscription television service and it means more competition for television delivery. IPTV is a nonstarter on current-generation broadband technology because the video bitrates are not high enough to offer sufficiently-attractive video quality.

One benefit of IPTV is that it allows more two-way participation, meaning that IPTV applications will be interactive and not limit viewers to passively watching movies or television shows. The viewing experience will be enhanced with a rich set of contextual information pertaining to the characters and their environment. Watching a high-definition episode of *Sex and the City* and like the outfit Carrie Bradshaw is wearing or the purse she is carrying? The interactive IPTV experience will allow the viewer to not only mouse over and click on her character to find out the designer, it will also present an interface allowing one to purchase it in real-time from the retailer. Broadband will enable such context-based services that both enhance the viewing experience and present new business models for retailers and broadcasters alike.

Another benefit of IPTV is that because it uses what is called switched video architecture it can offer customers video on demand and the highest range of channel selection. Instead of broadcasting every video channel to every customer whether they want it or not, switched video architecture means the service provider can deliver only the channels that the customer is watching (freeing up a substantial amount of bandwidth). IPTV in the United States currently supports 2 high-definition television sets simultaneously per broadband connection and will eventually support 3 and 4 simultaneous HDTV channels.

BOX 2: THE NEED FOR MORE NETWORK MANAGEMENT

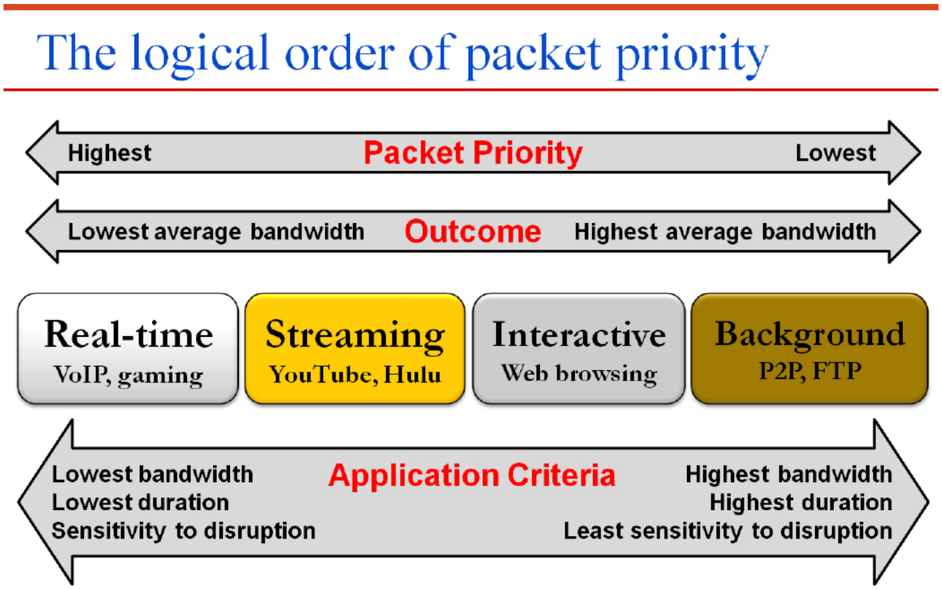
For the Internet of the future to operate effectively at high speeds, it will require not only more bandwidth but also more intelligence in order to ensure equitable bandwidth sharing between different applications and different users, to offer good simultaneous application performance, and to ensure minimal and consistent packet delay for all the applications that run on it. To accomplish these three goals, intelligent network management must be deployed inside the network. This is necessary for the following reasons:[31]

- No matter how much bandwidth a network can offer, some applications will always try to grab tens or hundreds of times more bandwidth than other applications, meaning the network must seek to balance the traffic as fairly as possible. Peer-to-peer (P2P) file transfer applications for example will automatically fill any network to 100 percent utilization no matter how big the network capacity is and will do so at the expense of other applications by leaving them with only 1 to 5 percent of the remaining capacity (Figure 7). For this reason, an equitable network must strive to make all applications work as well as possible while being as fair as possible. To achieve this, lower bandwidth and lower duration applications should always receive higher priority than higher bandwidth and higher duration applications. The outcome of this priority scheme is that lower bandwidth and lower duration applications will perform better while higher bandwidth and higher duration applications will perform the same and still get the highest average bandwidth from the network despite having the lowest priority.

- Broadband services need to be more hospitable to running multiple applications simultaneously as broadband connections are shared by multiple computers and devices within each home. When supporting multiple applications, intelligent networks can offer popular interactive applications, such as web surfing, much higher performance without negatively impacting background file transfer applications such as P2P.

- Packet delay comes in the form of latency and jitter. Latency is the minimum time it takes small pieces of data called packets to go from one computer to another over a network, while jitter is the variation in the time it takes packets to arrive. Latency can be problematic but it is manageable for the most part. Jitter is far more problematic because the length of the delay can be far greater and because it isn't predictable. Jitter can severely impact real-time applications like voice and video communications, meaning that managing jitter will be important to preserve high-quality videoconferencing and telepresence experiences. The good news is that jitter can be almost entirely eliminated with sophisticated traffic engineering techniques used by intelligent networks.

FIGURE 7: ORDER OF PACKET PRIORITY



BOX 3: THE RELATIONSHIP BETWEEN BANDWIDTH AND VIDEO QUALITY

Consumers in the 1990s often wondered why when they purchased larger television sets, the video quality seemingly got worse. While larger TVs did not actually decrease in quality, they more-readily revealed the severe limitations in standard-definition television. The resolution and fidelity in standard-definition television was simply not sufficient for larger TV sets and it held back the adoption of larger TVs. That all changed towards the end of the 1990s with the arrival of high-definition television (HDTV) sets. Standards bodies like the Advanced Television Systems Committee (ATSC) called for high-definition video broadcast bitrates (the bandwidth required by video) of 15 Mbps and standard definition (SD) video broadcast bitrates of 4 Mbps. With higher-resolution HDTVs and higher-resolution HD transmissions becoming both common and affordable this decade, consumer adoption of larger HDTVs has grown at a rapid pace.

More recently, as web content providers like YouTube, ABC, and NBC Universal's Hulu service have begun to offer their version of "HD" video over the web, the definition of what constitutes "HD" video had to be substantially relaxed to deal with the limitations of consumer broadband. The new standard bitrate adopted by web content providers is typically between 2 and 2.5 Mbps, which is even lower than SD digital broadcasts over the air. Indeed, the actual quality of the "HD" content over the web is sometimes lower than SD broadcasts over the air because the bitrate simply cannot deal with complex moving images without sacrificing quality.

While some would argue that advancements in compression technology allow higher compression without loss in quality, actual field tests show this to be false. Cable and satellite television providers that have reduced bitrates to accommodate more HD channels have been widely criticized for the obvious reductions in video quality.[32] The reality is that there is no substitute for higher bitrates and higher bandwidth when it comes to video quality. The only way to accommodate broadcast quality bitrates of 15 Mbps is to have broadband networks that support higher bandwidth. Only when next-generation broadband becomes ubiquitous will web content providers begin to offer higher bitrates and better video fidelity. While today's 2 Mbps "HD" web content may be good enough for a small window on a webpage on a computer monitor, the limitations quickly become obvious when the video fills out a large 46" HDTV. Companies like Verizon, which have deployed fiber to the home service to their customers, have enough bandwidth to offer 15 Mbps video on demand services to their customers today.

The bandwidth consumption of today's Internet video streaming services (in the United States) are predominantly 2 to 2.5 Mbps and occasionally 4 Mbps, but the bitrates must be increased to at least 8 Mbps to reach a level comparable to cable, IPTV, and satellite TV services. Going forward, as 120 Hz LCD HDTVs become increasingly common, video will be presented in 60 frames per second (fps), or even in stereoscopic "3D" video, presenting 120 frames per second to both eyes. This will double or quadruple the minimum amount of bandwidth needed for video to 16-32 Mbps. Within the next decade, 2160P "QuadHDTV" will come onto the market, driving demand for bandwidth consumption up to 64 Mbps for good-quality 2160P. On the technology frontier lies Ultra High-definition Video (UHDV), with which Japan is currently experimenting. Ultra High-definition Video, operating at 7680x4320 resolution and requiring 256 Mbps, will bring cinematic quality video to wall-to-wall video displays, and will eventually become as common and affordable as the 1080P HDTV sets of today. Ultra High-definition television and video will require substantial amounts of and become a leading consumer of broadband going forward.

Finally, a key benefit of IPTV for consumers is the increased competition in the television service market. IPTV services are compelling enough in price and service that those countries leading next-generation broadband deployment (e.g. the Netherlands, France, South Korea, and others) have high adoption rates for IPTV. In fact, ABI Research predicts that IPTV will soon overtake cable and satellite television as the primary source of TV worldwide, growing to 79 million subscribers globally by 2014.[33]

For example, IPTV has become broadly adopted in South Korea, as many South Korean citizens receive their television channels directly through the Internet, allowing them to use a wealth of interactive services associated with their television viewing. A very popular one is "live chat blogging" movies or television shows with friends or family who are watching elsewhere. Essentially, you and your friends or family can download and watch (or watch a currently-playing) movie or TV show from different locations (even across the country) simultaneously via IPTV, which comes with an interactive chat application at the bottom corner of the screen where viewers can post comments to one another while watching the show. Also popular via IPTV in South Korea are karaoke, gaming, online banking, and reading the morning newspaper directly from the HDTV screen. This convergence of televisions, computers, and telecommunications into a single platform is not to be underestimated. In fact, South Korea recently merged its Broadcasting and Telecommunications-regulating agencies together in recognition that device convergence means that consumers will increasingly interface with television, telecommunications, and computing through a single smart platform in their home.

The applications running over the Internet on next-generation broadband networks will look very different from those running on today's.

Online video websites like Hulu (from NBC), Netflix, and YouTube are increasingly becoming an alternative to subscription television services, and some consumers have stopped subscribing to traditional paid-television services like cable or satellite. While this hasn't happened on a large scale yet (as subscription television services have actually grown in 2008),[34] the migration to Internet-based television will accelerate as broadband performance rises and as televisions become directly connected to the Internet, creating opportunities for content providers to cut out the middleman and broadcast their television channel directly over the Internet.

Another application that requires much faster upstream bandwidth is place-shifting. For example, Sling Media makes a product that allows consumers to retransmit their cable or satellite TV services to anywhere on the Internet. This allows consumers to watch content that they have purchased, downloaded, or recorded from their laptop or another computer anywhere in the world. Unfortunately, most current-generation broadband connections are limited to less than 0.5 Mbps upstream and this effectively limits the quality of place-shifted video to low-resolution, poor-quality video. With next-generation broadband, place shifting devices will be able to offer high-resolution, high-quality video.

In general, next-generation broadband is facilitating a text-to-video transition in how Internet content is consumed. For example, YouTube has already become the second most popular search engine after Google, demonstrating consumer interest in consuming Internet content through rich visual media.

Next-generation Broadband Supports Real-time Collaboration

Next-generation broadband opens up a new world of opportunity for two-way, real-time collaboration, making it possible for individuals to have live visual exchanges with friends, family, business associates, corporate offices in other parts of the country or world, and service providers like doctors or attorneys. Advanced videoconferencing, or telepresence, as it is often referred to, will be one of the most transformative applications, enabling real-time, face-to-face collaboration through high-quality, two-way video exchanges, with applications being found across a wide range of professional, medical, educational, entertainment, and personal contexts.

The real time collaborations next-generation broadband enables also include working at a distance in real-time with colleagues on data-intensive projects like building computer-aided designs (CADs) for engineering or manufacturing, designing computer animations, or designing print and Web publications. Other collaborations will take the form of film and television production teams working across great distances in immediate high-definition collaboration with directors, editors, effects specialists, and on-location crews.[35] New multiplayer games and game engines will allow players to exchange all forms of rich media and information between each other in real time as part of the game, radically changing the fundamental design of games. The explosive growth of interactive websites like Second Life and the World of Warcraft illustrate people's appetite, as social beings, for this kind of ubiquitous real-time collaboration with other humans.[36]

While telepresence systems are emerging first in commercial environments, consumers will likely soon realize tremendous benefits from this application. Videoconferencing and telepresence applications will allow citizens to participate from their home in visual and interactive situations that redefine how they experience education, the provision of medical and public services, interactions with government, and access to the arts, sciences, and sports.

But perhaps the most transformative aspect of next-generation broadband's ability to enable real-time collaboration is that it significantly enhances the ability to work from home, or telecommute. Telepresence systems will let telecommuters participate in meetings at the corporate office just as if they were actually there. Moreover, quite a large number of business tasks—including video editing, market consulting, game development and serving, engineering and drafting, scientific sample analysis, software development, running complex simulations, and other types of independent content creation—can be performed remotely with a high-speed broadband connection, but not with today's typical broadband connections.[37]

A key attribute of next-generation broadband networks is not just its much faster download speeds, but also its much faster upload speeds.

Indeed, fiber networks have quadrupled the amount of time employees spend working from their home.[38] On average, those who telecommute save an hour of commuting time each day. Recent research has found that if all Americans had fiber to the home, this would contribute to a 5 percent reduction in gasoline use, a 4 percent reduction in carbon dioxide emissions, $5 billion in lower road expenditures, and 1.5 billion commute hours recaptured.[39]

As ITIF has reported, "thanks to its potential to cut costs, increase productivity, and expand the supply of potential employees, telecommuting is emerging as a standard for a large number of organizations."[40] In fact, with the increase in telecommuting spurred by advances in information technology—especially higher-speed broadband—the number of jobs filled by telecommuters could grow nearly four-fold to 19 million by 2012, positioning telecommuting to become more popular than transit and non-household car pools as a means of accessing work.

The vision of telepresence from the home is not far off. High-end personal computers already have both the computing power and the high-resolution LCD displays needed to handle telepresence. Even today, telepresence appliances that plug into existing HDTVs can be mass-produced for a few hundred dollars and prices will soon drop even lower. Since most consumers do not have next-generation broadband, bandwidth is one of the key missing pieces of the puzzle. Once next-generation broadband is prevalent, we can imagine a near future where inexpensive HDTVs (in many rooms of the home!) become a telepresence portal to the rest of the world via the Internet. And as Doug Koshima, the CEO of Japan's Sharp commented, "In ten year's time, entire walls in homes will consist of electroactive screens."[41]

Cloud computing

Bringing computers to the masses

The personal computer revolution put the power of computers into the hands of a billion people—now the challenge is reaching the next billion. Experts have long envisioned a future of smart terminals and powerful centralized servers allowing consumers to realize the benefits of computing and Web access without the expense or complexity of owning a personal computer. The concept was called "network computing" back in the 1990s (its vision perhaps best-encapsulated by Sun Microsystems' then-mantra that "the network is the computer"), and has more recently been renamed cloud computing. Cloud computing means that applications (and data) no longer have to be stored on one's computer hard drive, but can be stored remotely. The benefits of storing applications and data remotely from the computing platform include that: 1) the applications no longer have to consume and thus free up valuable space on the computer; 2) the applications can be managed and upgraded remotely, so that one doesn't have to contend with upgrades and version management; and 3) that applications can run across all the devices one owns, from computers, to HDTVs, to PDAs and cell phones. Cloud computing means that "thin clients," that is, light computers with basic levels of storage memory and processing power, can run complex applications, because those applications are not stored on the computer but rather "called up" from the Internet to run on the computer only when the user needs them.

Cloud computing did not materialize as many had envisioned in the 1990s for several reasons. First, then-popular "network computers" were actually more expensive than the conventional computers they sought to replace, despite having fewer features. And because television sets did not then have the resolution and detail required to display computer text and graphics, any device attempting to substitute for the personal computer had to include a display (which constitutes a significant portion of the cost of any computer). Second, network computers could not offer the richness of the personal computer because there was insufficient bandwidth in broadband networks to support video.

Today, many of the factors that contributed to the initial failure to realize cloud computing have been resolved. First, television set top boxes designed for video playback have more than sufficient computing power to operate as basic computers or cloud computing terminals. Second, almost all LCD television sets sold today (for as little as $200 at 19" displays or greater) have sufficiently-high resolution and the necessary digital inputs to also act as computer displays. As LCD HDTVs become more commonplace, the last missing piece of the puzzle is a network that is fast enough to support a cloud computing terminal, and this is where next-generation broadband completes the solution. Since the cost of the computer display is effectively paid for when consumers purchase an HDTV, with just a keyboard and set-top converter they can access a full range of Web-based applications without having to incur the expense of purchasing a new personal computer. When web pages, email, instant messaging, web streaming, and everything else the computer-literate population takes for granted arrives on the television set with push-button ease, "computers" will reach a much wider audience.

Computing without a computer is not just a dream; it is a reality in South Korea today through the widespread deployment of next generation broadband and IPTV. Because IPTV is interactive, South Korean citizens can already bank online (Figure 8) and view video on demand directly from their television set. Coupled with an inexpensive wireless keyboard that costs less than $20, HDTV can bring the Internet to citizens without computers.

Storage and applications

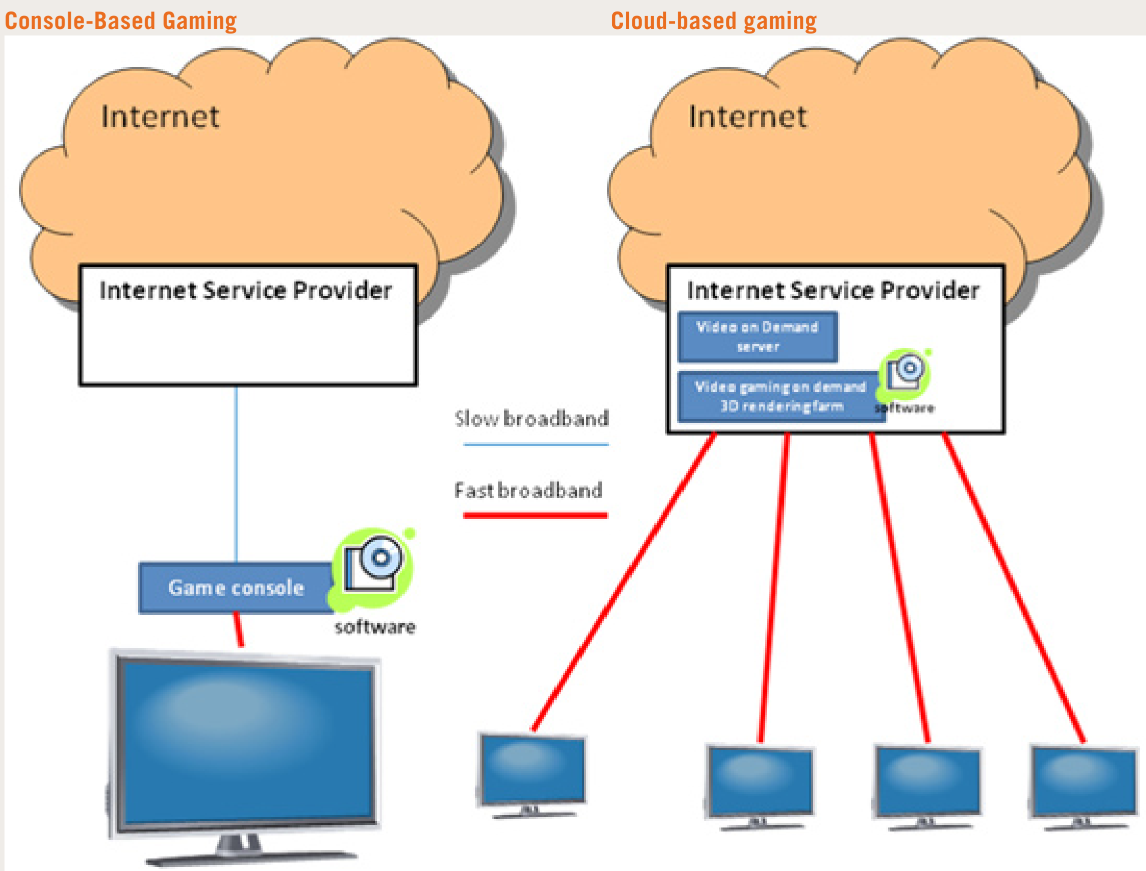
Cloud computing is not just about bringing computing to the masses; it also provides a means to access data anytime and anywhere. One of the key problems associated with conventional personal computing is that when people leave home or their workplace, they have no access to the data or applications they left there. Furthermore, data and applications stored at home or the workplace are not easily shared with other people. Cloud computing solves this problem by storing data and hosting applications on servers located within the "Internet cloud."

FIGURE 8: ONLINE BANKING THROUGH AN HD TELEVISION IN SOUTH KOREA[42]

Though they may not be aware of it, consumers already use cloud computing today for email and calendar applications like Google Gmail and Microsoft Live. But due to limited bandwidth, it is impractical to store more than text, medium-resolution images, and an occasional low-resolution video on the Internet. Once next-generation broadband exists, it will be practical to store more data on the Internet cloud and run a much wider range of applications from it. In effect, computer memory and processing power on the desktop can be supplemented—and even supplanted—by the storage memory and processing power of the Internet cloud and the transmission speed of the network. The implications are profound, as this significantly lowers the threshold for entry to citizens who have previously lacked the means to purchase personal computing solutions. Thus, cloud computing enabled by next-generation broadband networks can go a long way towards addressing the "digital divide" in the United States by making computers easier to use and improving their functionality.

Cloud computing also has the potential to reinvent the computer gaming experience. Today, consumers must purchase gaming computers or video game consoles along with software titles. The video game industry also suffers from rampant game piracy when games are sold in this business model. In the future, consumers will be able to simply subscribe to a cloud-based video-game-on-demand service and play online 3D gaming at 1080P HD resolution with Hollywood realism without any hardware inside the home. Consumers could have access to an entire library of games with nothing more than a wireless gamepad controller and their existing HDTV. With next-generation broadband networks, the 3D rendering could be generated at a data center using high-end 3D rendering farms and the real-time video stream could be piped into the

FIGURE 9: CONSOLE VS. CLOUD-BASED GAMING



customer's HDTV at 40 Mbps, equivalent to Blu-ray video quality with very low latency. Figure 9 depicts how this "cloud-based gaming" service would work.

The online gaming and social networking software industry in Korea has been hugely successful due to the popularity of both wired and wireless broadband services.[43]

Finally, another consumer benefit of ubiquitous next-generation broadband will be the realization of "smart homes" with features including intelligent appliances and video home security devices that can send video feeds back to the home security company's emergency operations management center, or to residents at another location. Intelligent appliances will be connected to smart meters, enabling consumers to control their energy usage based on dynamic price signals that fluctuate throughout the day in response to energy supply conditions or energy cost during periods of peak demand.[44] Intelligent clothes dryers, for example, might cycle off for short intervals during peak energy demand periods, while smart refrigerators order food and select optimal energy consumption settings. Smart homes can be programmed remotely, for example, to let repairmen in at specified times, to turn the air conditioning or heating on or off at appointed hours, or even to instruct the oven to preheat or start cooking meals at a certain time.

BENEFITS TO SOCIETY

Deploying next-generation broadband will benefit American society in a number of ways, including: enhancing the quality of medical care through telemedicine; enhancing participation in society for citizens with disabilities or disadvantages; improving access to the arts, sciences, and sports; facilitating governments' ability to connect with citizens; and even helping first responders deal with emergencies.

Health Care Delivery

Next-generation broadband makes possible entirely new life-saving or -enhancing technologies and services in the medical field. It can enable instantaneous contact between health professionals and patients, remote patient monitoring and diagnosis, and more efficient management of chronic diseases, especially for citizens who live in remote areas without access to specialists or urban medical care.[45] We examine several applications of telemedicine, including teleconsultations and remote diagnosis, teleradiology, digital pathology, remote surgery, and home health (remote) monitoring.

By making high-quality, real-time two-way video conferencing practical between home and a doctor's office, next-generation broadband broadens opportunities for patients to "teleconsult" through video-conferences with their doctors. For example, Cisco's

BOX 4: 3D RENDERING FARMS USING NEXT-GENERATION BROADBAND

With next-generation broadband operating at 50 Mbps and beyond, one potential cloud application is 3D rendering "farms" coupled with real-time high-definition video output transmitted over the Internet. Engineers, geologists, production studios, mining companies, and medical and geological professionals will be able to access state-of-the-art cloud-based 3D rendering farms.

A 3D rendering farm is a bank of high-powered computers with specialized graphics computing power working together to make a realistic 3D image or series of images used in a video sequence. It is not possible (without a supercomputer) to generate this level of detail on a single computer. For example, the kind of fancy visual sequences in most blockbuster Hollywood movies like Transformers have to use 3D rendering farms to generate complex images. But 3D rendering is not just for entertainment; it is used in the fields of mining, science, and medicine. Mining companies have to render complex underground terrains before they decide where to drill. Doctors use 3D rendering to model the inside of the human body using data derived from MRI scans. The on-demand video preview for these applications requires a minimum of 64 Mbps to 128 Mbps to support Quad HD 3840x2160 resolution displays.

HealthPresence uses the network as a platform that allows patients and doctors to interact over a secure connection through high-definition audio and video, allowing doctors to obtain vital signs and diagnostic information from their patients by using special network-enabled medical devices.[46] Some applications attach medical instruments to videoconferencing equipment to diagnose particular diseases or conditions. UC Berkeley, for example, uses this kind of "remote instrumentation" to perform retinal scanning for diabetics (annual checkups to ensure that diabetes is not compromising their eyesight).[47] Teleconsultations can also benefit citizens who are immobile or live in remote or rural areas and need to be seen by specialists or experts in a particular disease. This obviates a trip to the doctor's office for patients for whom mobility may be difficult.

Deploying next-generation broadband benefits citizens by enhancing the quality of medical care through telemedicine; enhancing participation in society for individuals with disabilities or disadvantages; improving access to the arts, sciences, and sports; and facilitating governments' ability to connect with citizens.

Remote radiology, or teleradiology, which requires the transmission of extremely detailed radiological images containing tremendous amounts of information, works optimally over high-speed broadband networks, and is capable of delivering substantial social benefits.[48] For example, the U.S. Indian Health Service deploys mobile mammography vans that travel to remotely-situated patients, scans them in the van, and transmits the radiological images to remote doctors, who are able to provide a real-time diagnosis.[49] Another UC Berkeley team has developed an affordable, portable MRI technology called prepolarized MRI (PMRI). PMRI machines, at $50,000 a fraction of the cost of conventional $1.5 million MRI machines, make it possible to expand the range of disease states that can be cost-effectively diagnosed by MRIs, such as infections of the diabetic foot (a common complication and major contributor to amputation, morbidity, and disability).[50] Connected via high-speed networks to the appropriate medical specialists, PMRI is positioned to dramatically expand the use of diagnostic radiology.

Next-generation broadband can also enhance medical outcomes by enabling grid computing. Digital mammograms use the same X-ray science as older mammograms, but using a digital receiver in lieu of film yields a number of benefits, including less radiation exposure for the patient, immediate lab results, and most importantly, more accurate readings.[51] In addition, electronic storage and transmission of mammograms allows doctors to easily compare mammograms from multiple years or patients to provide more accurate diagnosis.[52] The European MammoGrid project created a European-wide geographically distributed database of digital mammograms, which allowed radiologists to make comparative diagnoses with other images from the databases.[53]

Next-generation broadband also makes realistic the potential of telesurgery. Using high-speed networks to transmit real-time audio, video, and health data, surgeons can remotely operate robotic arms in an operating room thousands of miles away. For example, one patient in Guam recently underwent a life-saving heart operation supervised by an expert doctor located 3,500 miles away at Tripler Army Medical Center in Honolulu. The surgery was relatively routine for Dr. Benjamin Berg, who was able to dictate the procedure to a less experienced colleague, monitoring every move and heartbeat through a high-resolution video camera and sensors that instantaneously gathered data from the catheter as it was slid carefully into the right chamber of the patient's heart.[54]

Japan is a world leader in telemedicine. The country is developing cutting-edge broadband applications in digital pathology, and is ensuring all its citizens have access to the highest-quality medical care, even if they live at great distances from urban centers. Since August 2007, doctors at Kanto Medical Center in Tokyo, including director of diagnostic pathology Shoji Matsuya, have used a telepathology system developed by NTT (Japan's largest telecommunications provider).[55] The service allows pathologists—using high-definition video and remote-controlled microscopes—to examine tissue samples from patients living in areas without access to major hospitals. Those patients need only find a clinic with the right microscope and a fiber connection. Dr. Matsuya noted that telepathology will help Japan deal with a severe shortage of pathologists and observed that, "Before, we did not have the richness of image detail. But with this equipment, I think it is possible to make a definitive remote diagnosis of cancer."[56] Another system developed by NTT helps small-town doctors by relaying images of cell slides, X-rays, and other medical data to pathologists in well-staffed city hospitals.[57] Also, Hitachi has developed a rubber mat that can monitor and transmit a person's pulse, blood pressure and other data to the patient's physician.[58]

Despite having the world's fastest broadband network,[59] Japan, still not satisfied that all citizens had the ability to access that network, launched in February 2008 Kizuna, an experimental Internet satellite. Kizuna is designed to bring extremely high Internet speeds to rural and other areas (such as its remote islands) that have been left off the country's Internet grid. Whereas American consumers are familiar with satellite-based Internet services operating at speeds of perhaps several megabits, Kizuna expects to provide Internet download speeds of 155 Mbps, with upload speeds of 6 Mbps.[60] As Japan's Aerospace Exploration Agency (JAXA) explains, Kizuna's most valued asset is its ability to bring applications requiring high-speed broadband to even the most remote Japanese citizens:

> With Kizuna we will be able to contribute to "remote medicine" that enables everybody to receive sophisticated medical treatment regardless of time and location by transmitting clear images of the conditions of a patient to a doctor in an urban area from a remote area or island where few doctors are available.[61]

High-speed broadband in South Korea has also allowed medical services and research to begin moving outside hospitals and doctors' offices and into patient's homes. South Korea's u-Health Aide system uses broadband networks both in hospitals and homes to remotely measure vital signs, transmit data, and allow health care providers to respond without the patient ever leaving home. South Korea also commonly uses broadband to provide medical services to prisons via remote teleconsultations. Because prisoners cannot leave the prison facility, doctors are "brought in" via the Internet and consultations are performed over a video-conferencing session. This brings the doctor to the patient electronically, in many cases obviating the need for an in-person consult.

Next-generation broadband will have a considerable impact on patient care monitoring, both in-hospital and in-home. One novel application that leverages next-generation broadband to provide real-time patient monitoring is an eICU (electronic intensive care unit), such as VISICU by Philips. Such remote intensive care units create an "air-traffic control center" using telepresence to centralize real-time views of patients in their hospital rooms, combined with charts, radiological images, medical histories, and real-time data and alerts.[62] The result is that more patients can receive better quality care by having 24/7 access to intensivists (physicians who specialize in caring for ICU patients).

Next-generation broadband can enable instantaneous contact between health professionals and patients, remote diagnosis of disease or illness, remote patient monitoring, and more efficient management of chronic diseases, especially for citizens who live in remote areas without access to specialists or urban medical care.

But the in-home care monitoring that next-generation broadband enables will have an even broader impact. With high-fidelity video communications empowered by next-generation broadband and wireless medical sensors, computer systems and doctors will be able to remotely monitor patients living in the comfort of their own home. For example, the Renaissance Computing Institute in North Carolina has developed an Outpatient Health Monitoring System (OHMS) for patients with chronic conditions such as asthma. The OHMS uses multiple wireless sensors to monitor both a patient's condition and environmental factors that might affect their condition (such as pollution, allergens, temperature, and humidity). Using an OHMS, patients can work with their doctors to more effectively manage their health before crises arise.[63]

The videoconferencing capability enabled by next generation broadband is also being used by social service agencies to enable remote supervision in adult foster care settings. Non-profit Home and Community Options (HCO) of Winona County, Minnesota created an adult care remote monitoring system that features remote video supervision of all public spaces; high-quality video-conferencing capability; remote two-way audio communication; a security system linking alarms to the remote monitoring system; and a call escalation program that guarantees physical presence in case of emergency. HCO has found that the remote monitoring and supervision of its clients has increased its cost-effectiveness while increasing the client's autonomy.[64]

Economist Robert Litan has found that expanded broadband deployment among seniors and persons with disabilities will result in cumulative savings and output gains of at least $927 billion by 2030.[65] Broadband achieves this in three ways, by directly lowering health care costs, by postponing or obviating the need for institutionalized care, and by promoting increased workforce penetration. Litan finds that these output gains could increase by an additional $532 billion by 2030 with more aggressive broadband deployment policies.

Universal Accessibility for Citizens

Next-generation broadband will help increase participation for citizens with disabilities, with low incomes, or who are not native English speakers. For example, the firm Snap!VRS provides sign language video relay services for deaf citizens. It uses videophones to connect deaf citizens with sign language interpreters who facilitate medical care (e.g. teleconsultations with doctors) or interactions with government agencies.[66] Many people with disabilities have found that high-speed broadband Internet access provides them with unprecedented ability to access information, services, and opportunities. Whether a person has a mobility impairment or chronic fatigue, options such as telecare and telework can improve their quality of life. Telework allows people with disabilities who are unable to commute to be able to work from their home, a convenience that can mean the difference between

BOX 5: NUMENTA CASE STUDY

Numenta (www.numenta.com), founded in 2005 by Palm Pilot-inventor Jeff Hawkins and one of Silicon Valley's most exciting start-ups, is working on one of the most ambitious goals imaginable: building computers that work like the human brain. Through exploring the inner workings of the brain, Numenta's programmers have replicated the information processing mechanisms of the neocortex through a Hierarchical Temporal Memory (HTM) system that uses some of the most complex mathematical algorithms ever devised.[67] The process can be used on problems that involve identifying patterns in complex data, and its applications will include vision systems, robotics, data mining and analysis, and failure analysis and prediction.[68]

Subutai Ahmad, Numenta's VP of Engineering, explains that the availability of next-generation broadband could dramatically accelerate the adoption of its technology and deliver societal benefits. One of the first applications of Numenta's software is in digital pathology, helping doctors determine whether tissue samples contain cancer cells based on the identification of key markers. Just as pathologists must train on samples, so must Numenta's software be "trained" on the data, a process requiring its software to learn from thousands of digital images, each over a gigabyte in size. To collect that number of images, Numenta staffers literally have to drive around Silicon Valley, load image samples onto computers, and drive back to their lab. A next-generation broadband network capable of handling these data-intense images would obviate that need.

A next-generation broadband network would also enable application of Numenta's technology in monitoring in-home care of elderly or post-operative patients. This solution entails feeding the data collected by a combination of high-resolution video cameras and remote biometric sensors via high-speed broadband to Numenta servers that evaluate the data and make predictive assessments of whether additional medical intervention is required. There are several applications of this in the home. The technology could ensure that post-operative patients are recovering well and taking their prescriptions on schedule. Alternatively the system could monitor elderly parents to ensure that they have not fallen down and are unable to get up. Ahmad explains that, "Next-generation broadband is critical for enabling such applications—with today's broadband speeds, we have not found it possible to reliably stream the necessary high quality real-time video to support remote monitoring applications."[69]

Ahmad also observes that, "One of our biggest challenges is connecting disparate data sets with the people who have the expertise to analyze the data. If all these, often extremely large, scientific data sets were readily available for download, we'd see an awful lot more innovation from developers finding creative applications for our technology."[70]

employment and unemployment. In addition, working from home may provide citizens with disabilities a more accessible and flexible work environment. Telework also benefits companies who can use this benefit to retain productive employees who face short-term or long-term disabilities.[71]

Widely available next-generation broadband could transform the provision of public health services as well. The City of San Francisco, for example, has 23 public health centers—and 112 languages spoken by its residents—making it a difficult task to connect many citizens with a public health provider who speaks their language. San Francisco's Public Health Department is installing high-end videoconferencing equipment so that individual centers could be connected with a centralized staff of foreign language speakers to facilitate three-way conversations with physicians. Broadly deployed next generation broadband network is necessary to implement such a program. In another example, Fort Wayne, Indiana, which has an extensive fiber-optic broadband system deployed by Verizon, has set up a system where retired nurses help provide health evaluations for low-income residents without health insurance through means of two-way broadband connections.[72]

Arts, Humanities, and Sports

Next-generation broadband will also facilitate access to the arts, humanities, and sports. It will allow citizens with a high-definition television screen to participate in tele-immersive environments including the staging of plays performed across multiple stages, or concerts performed in multiple concert halls. Universities are already using this technology to enable virtual rehearsals for choreography and dance. For example, a world-renowned choreographer at Florida State University uses video to offer tele-coaching to students at other universities through virtual rehearsals. Similar technology has been used to create virtual studios to allow international music experts to offer trans-Atlantic music lessons through live high-quality video feeds.[73]

Sports over a distance is a novel combination of next-generation broadband and telepresence systems that has been shown to foster bonds between people over large distances. Early versions included the Virtual Tug-of-War and the NetGym, which joined two physically-separated exercise bicycles in a virtually-connected gym through a physical (screen) interface in which the cyclist rides with an avatar representing the remote user (to foster the interaction component).

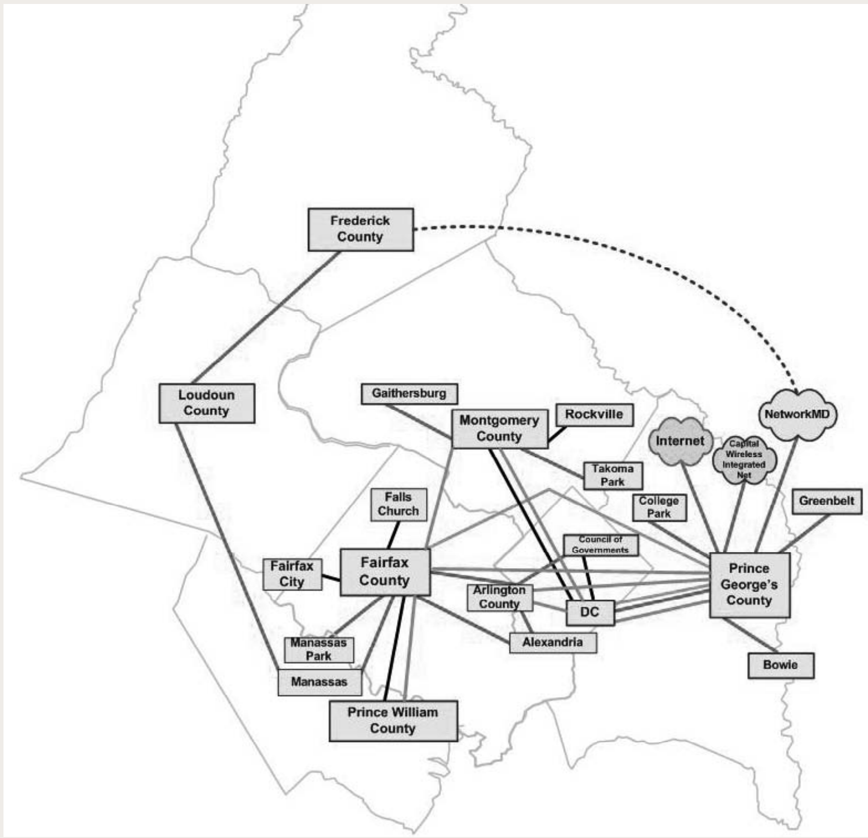
Another application creates virtual "exertion interfaces" (Figure 10) where players, who can be miles apart from each other, both throw or kick a ball against a local, physical wall, on which appears a projection of the remote player, enabling the participants to interact with each other through a life-sized video and audio connection.[74] The experience is akin to a tennis match, with each player occupying his or her part of the "field" and the wall representing the net or boundary between the players, over which they communicate. The effect is to facilitate social interaction and encourage conversation between the players. The intent is to enable social relationships to form through interactive sporting games in which physical exertion is required, even if the participants are physically distant, perhaps even on opposite sides of the world.[75]

FIGURE 10: SPORTS OVER A DISTANCE

Government and Civic Life

Next-generation broadband will facilitate governments' ability to deliver services, and help citizens better connect with their government. The civic process is improved the more government agencies place videos of meetings or hearings online, and the more citizens have the high-broadband speeds needed to rapidly download and watch these videos. President Barack Obama has pledged to put the proceedings of the federal government online, including providing live webcasts of Congressional hearings and agency

FIGURE 11: NATIONAL CAPITAL AREA NETWORK (NCRNET)



meetings, and this should spark a flood of new video content streaming from government agencies. As governments and agencies at the federal, state, and local (including school boards, town halls, and county and city councils) levels increasingly post videos of their meetings online, next-generation broadband will become essential for empowering citizens to engage in civic affairs.

Access to next-generation broadband is also increasingly important for police, fire, and emergency medical personnel as a means to respond to crises. More than 90 percent of the nation's public safety infrastructure is financed, owned, operated, and maintained by more than 60,000 separate, independent local jurisdictions and police, fire, and emergency services. Public safety personnel operate on 10 different frequency bands, and their equipment, sometimes more than 30 years old, is frequently incompatible. Next-generation broadband would enable first responders to share text, images, and video across jurisdictional barriers.[76]

A success story comes from the Washington, DC metropolitan region where the fiber optic National Capital Area Network (NCRnet), shown in Figure 11, connects the emergency response managers from 21 local jurisdictions and two states in a regional public safety communications network. NCRnet lets local government agencies and organizations share critical data and information both during emergencies and day-to-day operations, interconnecting public safety databases, communications, and functions.[77] A video-conferencing application runs on the network, allowing emergency response managers to convene in real-time in the event of emergencies (or for normal meetings and interactive training between jurisdictions). Other applications hosted on NCRnet include geographic information systems, computer-aided dispatching of first responders, full-motion traffic-camera feeds and intelligent transportation systems, and regional automated fingerprinting enabling law enforcement to share fingerprints and mug shots.[78]

The City of San Francisco sees next-generation broadband as indispensible for its citizens, community, businesses, and governance. As San Francisco CIO Chris Vein explains, "Next-generation broadband is foundational and transformative, and is as essential an infrastructure as water or electricity. We envision a future where every city building and service is supported by fiber, from schools and libraries to public health agencies and mental health clinics. Having next-generation broadband is also crucial to the quality of life and educational and economic opportunities for our citizens and for the competitiveness of our businesses."[79] The city's Network of Connected Networks has connected 2,300 of its 5,200 federally-subsidized housing units with next-generation broadband at speeds of 30 to 100 Mbps, over which it provides tailored content such as classes on a number of subjects taught in three languages: Cantonese, Russian, and Spanish.

Vein envisions broadband helping the city tackle challenges such as health care and traffic management. He notes the city's broadband network "provides an infrastructure that medicine can take advantage of, including teleconsultations, automated patient records, and improved patient education and information sharing." Vein also notes the city is piloting a program allowing citizens to reserve and pay for parking meters online, and says he expects next-generation broadband to be applied to intelligent transportation systems in the city, including traffic lights and the dynamic message signs that provide drivers alerts on highways. (Since many of these dynamic message signs around the country are connected to traffic operations centers (TOCs) by dial-up, the messages are often outdated by the time the TOC is able to get the message up).[80]

Next-generation broadband can help communities develop solutions that reduce carbon emissions, while still fostering economic growth, by increasing traffic efficiency, improving the efficiency and quality of public transportation, and creating sustainable workplace models, including telecommuting.[81] Seoul, Amsterdam, and San Francisco have united through the Connected Urban Development initiative to demonstrate that environmental, social, and economic stability can be achieved by introducing fundamental improvements in the efficiency of the urban infrastructure through an intelligent information and communications technology network. The initiative recognizes that, "It is the next-generation broadband network that enables the transformation of how residents work and interact with each other, how the city delivers services, and the delivery of new types of services that allow more efficient ways of living and working."[82]

Next-generation broadband networks have contributed substantially to South Korea being a world leader in e-government.[83] As Yunho Chung, a Korean IT industry analyst with Veyond Partners explains, "In South Korea, next-generation broadband is viewed as a platform to deliver social and public services, especially in the smaller communities, and one that has dramatically facilitated the adoption of e-government in South Korea."[84] *The 2008 UN E-Government Survey* noted that South Korea's strength in e-government, "is testament to the orchestrated manner of this Asian country to focus holistically on digital infrastructure both outside and within the public sector" and partially a product of the widespread availability of next-generation broadband networks.[85]

BENEFITS TO EDUCATION AND ACADEMIC INSTITUTIONS/UNIVERSITIES

Next-generation broadband has the potential to transform how education is delivered, supporting distance learning, enhancing the ability to perform research, for everyone from elementary school students to astrophysicists, and expanding the set of resources academic institutions can readily access.

Education

Whether at the elementary, secondary, or collegiate level, high-quality videoconferencing can provide interactive, two-way, real-time educational experiences: students who cannot be physically present in class (if they are at home or even a hospital) can continue to participate in regular classes and give presentations, parents can confer with teachers using videoconferencing, and study groups can form with members working collaboratively on projects as they remotely consult databases, video libraries, computer simulations, and each other.

In the United States, the Public Broadcasting System (PBS) seeks to transform the way early childhood education is delivered by layering broadband-delivered applications on top of content currently provided by the broadcaster. PBS's Education Digital Content Asset

Repository (EDCAR), now in the "proof of collaboration" stage, will be a comprehensive online digital library that gives teachers just the right video snippet, image, audio clip, or interactive simulation that they can plug into a lesson.[86] EDCAR will store thousands of "content assets" and applications available for on-demand download, keep logs of teachers' favorites, and include social-networking features for discussing teaching ideas with other educators.[87]

There is significant potential for using videoconferencing for a variety of educational purposes. In cases where school districts cannot provide a teacher of an advanced subject to every school—suppose a school district wants to be able to teach its students German, Korean, and Arabic—videoconferencing would enable a single teacher to teach one class to all students in the district interested in the course. High school students could use video telepresence to enroll in advanced placement (AP) courses from other high schools, community colleges, or universities.

Carnegie Mellon University, for example, is already using high-quality video to allow professors to teach classes without the constraints of geography, with professors teaching courses to students scattered throughout Carnegie Mellon's various satellite campuses around the world. Just as Amazon unlocked the "long tail" for book distribution, so too can video teleconferencing unlock a long tail for academic education, providing a much wider array of courses than are typically offered today in schools.[88] Video-based instruction could unlock new business models for universities, such as monetizing the lecture presentations of their best professors, as the firm The Teaching Company has done.

The use of virtual worlds as an educational tool is becoming increasingly common. For example, Virtual Harlem is a virtual reality reconstruction of 1920's Harlem, designed to help students experience the neighborhood's life and culture. First initiated by University of Missouri Professor Bryan Carter as a supplement to an African-American literature course, Virtual Harlem was further developed by the English department, communication department, and Electronic Visualization Laboratory at the University of Illinois at Chicago (UIC).[89] Supplementing a selection of literary works from the era, the Virtual Harlem prototype allows students to be immersed and engaged in the coursework. Students are able to navigate the environment, hear the city noise and samples of locally written and popularized music, and examine the architecture of storefronts and theaters.[90]

From a clinical training perspective, education and gaming technologies are now merging into learning-based simulations that will demand enormous bandwidth as they approach super-realistic "virtual reality." Haptic (force) feedback devices are being explored in both gaming and medical applications that can add "feel" to simulations; but to work they require zero latency and very fast broadband networks.[91]

Next-generation broadband has the potential to transform how education is delivered, supporting distance learning, enhancing the ability to perform research, for everyone from elementary school students to astrophysicists, and expanding the set of resources academic institutions can readily access.

In Japan, satellite-based broadband enables schools and researchers in remote areas to exchange information easily, eliminating the small time lag that often exists as communications are conveyed via relay stations, allowing remote students to communicate as if they are all in the same classroom. As Atsushi Umino, Deputy Director of Japan's Ministry of Internal Affairs and Communications (MIC) explains, the goal is for all Japanese schools to be broadband-connected so they can share knowledge regardless of the school's resources. As Umino explains, "This gives the teachers a great tool. They have a wider variety of teaching plans, [it] lowers the cost of supplies, and gives students in every school increased access to knowledge, regardless of their economic situation."[92] Thus, Japan intends to use high-speed broadband as a mechanism to transcend income inequality barriers as a means of encouraging social mobility.

South Korea has taken the same approach, with the government-funded Education Broadcast Service (EBS) helping to close the education divide between children in poorer rural areas and larger cities.[93] Recognizing that not all families would be able to afford to send their children to private "cram schools" to prepare for the national aptitude test, an SAT-like exam that can determine college admissions and future job paths, the government provides a public website where all students can access free tutorials for the national test.[94] Since these tutorials consist of video instruction, they require high speed Internet access. The intent is to provide broad access to education resources, thus "leveling the playing field" for South Korean students and allowing talent to blossom, no matter which part of the country it hails from.

Academic and Scientific Research

One of the most powerful ways next-generation broadband networks will transform education is through academic and scientific research. Because the "public" Internet has not been capable of handling transmission of extremely large data sets and video-intensive applications, researchers from 34 universities launched in 1996 an organization called Internet2 (www.internet2.edu) "to foster the development of networking capabilities that will not only support research and education, but will also eventually make their way into the global commercial Internet." Internet2, which offers end-users data rates of 100 Mbps, has pioneered the development of new applications that take advantage of this level of bandwidth capacity. While its reach is limited primarily to university campuses today, case studies from Internet2 demonstrate the types of applications that will become available once next-generation broadband is broadly deployed in the United States, and illustrate how key characteristics of those applications will differ as they are designed for tomorrow's networks instead of today's.

A primary use of Internet2 is for applications that rely on exchanging massive data files with bandwidth requirements not supported by today's public Internet infrastructure. Scientists in the United States can use Internet2 to gain access to data sets from research occurring around the world. Physicists, for example, use Internet2 to access research at the Large Hadron Collider—the world's largest particle accelerator—in Geneva, Switzerland.[95] Every few weeks, physicists following this research will have to download the most recently generated results, typically consisting of multi-terabyte (1,000 Gigabytes) data files.

A number of video-intensive applications—that today must use Internet2, but that would be readily available to the public on next-generation broadband networks operating at speeds of 50 Mbps or more—have been created to overcome geographic boundaries and increase public access to science and nature. For example, Mystic Aquarium partnered with the University of Connecticut to provide visitors access to underwater video cameras. The cameras are mounted to a submersible over 3,000 miles away and DVD-quality video feeds are streamed to the museum in real-time. Visitors can use an interactive console to control the cameras and explore marine life.[96] Remote instrumentation, or control of distant resources, is a common theme in many Internet2 applications. For example, the Gemini Observatory gives astronomers in Chile and Hawaii remote access to two mountaintop telescopes. The nanoManipulator project at the University of North Carolina, Chapel Hill gives scientists remote control of high-tech microscopes and uses high-definition video to create a "virtual laboratory" for remote collaboration and sharing results.[97]

Japan and South Korea use next-generation braodband to "level the playing field" in their education system as a means of transcending income inequality barriers and fostering social mobility.

Finally, a number of applications use Internet2's network capacity to implement cloud computing for research purposes. For example, the National Scalable Cluster Project (a prototype meta-computing system that aims to develop software and demonstrate scalable clustered computing) conducts data mining on massive amounts of data widely distributed geographically across the network. These types of large-scale data mining projects can be used to analyze massive (terabytes to petabytes) distributed data sets for purposes including atmospheric modeling, computational biology, and bio-surveillance. Other projects, such as TIDE2, use visualization techniques to display large, multi-dimensional data sets. The idea is to harness the power of the human mind to identify visual patterns in analyzing large data sets.[98] Other uses include the EVIA Digital Archive, a partnership between Indiana University and the University of Michigan, where a team of ethnomusicologists collect and archive video recordings of musical performances worldwide for educational and research purposes.[99] Another example is UC-San Diego's CAMERA project, which provides the scientific community with metagenomics data and software analysis tools, and is being used to look beyond the genomes of individual species, to analyze interrelationships between genomes in whole ecological communities.[100]

Telepresence and videoconferencing systems allow people to connect through information technology rather than fossil fuels, improving productivity, accelerating innovation, and benefiting the environment.

While some of the characteristics of Internet2 applications are emerging in today's Internet, they are not yet mainstream in large part because of current bandwidth limitations in the United States, whereas citizens in Japan, for example, would have the requisite bandwidth to readily access and leverage almost all of these resources.

BENEFITS TO BUSINESSES

Next-generation broadband will be crucial for the competitiveness of small businesses and large corporations alike. Furthermore, next-generation broadband contributes to the development of new business models, services, and forms of corporate organization.

Empowering Small and Home-Based Businesses

Home-based businesses can achieve much greater efficiencies from next-generation broadband capabilities. Quite a large number of business services—including video editing, market consulting, game development and serving, engineering and drafting, scientific sample analysis, software development, running complex simulations, and other types of independent content creation—can be performed remotely with a high-speed broadband connection, but not with today's typical broadband connections.[101] Next-generation broadband will thus be essential for enabling telework to become plausible for employees who need to leverage data stored on corporate networks, or to leverage and run complex, data-intense applications that reside either on their corporate server or in the computing cloud.

Korea Telecom (KT) has become a leader in the broadband services space. The company created a platform for small and medium enterprises (SMEs) called BizMeka that has grown into a $200 million business. There is so much traffic congestion in Korea that Korea Telecom often could not get its technicians from one customer site to another in time. The company saw an opportunity in this to leverage the country's high-speed broadband to offer managed network services—including PC support management, remote network monitoring, customer relationship management, groupware, conferencing, and surveillance/security services—to small and medium-sized businesses. BizMeka technicians are able to reboot damaged computers and install a new operating system from a remote location, including handling all extraction and reintroduction of data onto the hard disk. The remote hard drive backup service alone requires hundred of Mbps (even up to 1 Gbps) to execute. While such managed network services are offered in the United States, the interesting point about the BizMeka case is that because almost all SMEs have access to next-generation broadband in South Korea, KT was able to build a scalable business serving those customers because the customers had the network capacity to take advantage of the services—something many similarly-sized American firms still do not.

Supporting Professional Collaborations

As Professor Henry Chesbrough of Berkeley's Haas Business School writes in *Open Innovation*, the modern corporate innovation model has become one based on collaboration—simultaneously tapping into the best ideas and talent both inside and outside the firm instead of trying to build everything in-house, and next-generation broadband plays a critical and multi-faceted role in fostering corporations' ability to collaborate. The dispersion of talent and resources, not to mention the pressure on companies to cut costs and reduce environmental impact by scaling back travel, makes telepresence an indispensible collaboration tool.

Telepresence technologies allow for real-time virtual meetings that begin to create adequate substitutes for real face-to-face interaction. These technologies offer high-definition audio and video that allow participants to communicate with body language, making virtual meetings almost as lifelike as face-to-face meetings. Telepresence systems allow companies to curb travel (connecting people through information technology rather than fossil fuels), to improve productivity, and to accelerate innovation.[102]

Companies that have adopted telepresence report considerable success. Cisco expects to save $400 million this year in travel expenses through its use of telepresence and videoconferencing.[103] DreamWorks created a virtual studio collaboration initiative to allow their various corporate campuses to work on the same movie storyboard. The company was able to double the number of animated features it produces each year, and it credits telepresence technology as a key contributing factor.

Moreover, as corporations move to 24-hour production cycles, in many cases characterized by teams in Seattle, Shanghai, and London developing software or products day-round, next-generation broadband becomes crucial to their ability to actually transmit work product. For example, many of the leading computer-generated imagery (CGI) firms in the United States are located in Silicon Valley, but their clients are in Los Angeles. Because the CGI graphics are so data-intense, they cannot be readily emailed via the Internet to their customers in Hollywood, and at the end of each day must be burned onto physical hard drives (or CDs) and overnight expressed to Los Angeles. Transmitting these files electronically would not only be far more efficient and inexpensive, contributing to quicker turn-arounds and enhanced productivity, it would also obviate a substantial degree of physical waste. Unfortunately, as San Francisco CIO Vein notes, "A lack of next-generation broadband in the United States has hurt Bay Area digital media and CGI companies. The more sophisticated broadband networks in countries such as South Korea, Singapore, Japan, and even Canada place U.S. digital media firms at a disadvantage to international peers, and has caused job loss in the Bay Area."[104]

Another aspect of collaborative innovation has companies enrolling partners and customers to co-develop products and services alongside them. As Doug Neal of Computer Science Corporation's Leading Edge Forum explains, the model is, "You build the platform and they build the experience." As customers start

BOX 6: NETWORK EFFECT FROM NEXT-GENERATION BROADBAND

The network effects that next-generation broadband enable will also contribute to economic growth. A recent study by the Fiber-to-the-Home Council found evidence of broadband's network effect in spurring consumption of peripheral computer equipment, concluding that the average amount of peripheral consumer electronics purchased by each FTTH broadband subscriber was $370.50 (Table 4).[105] The study estimated that fiber to the home's estimated one-year economic impact (from Spring 2005 to Spring 2006) was $169 million in electronics sales, and that fiber to the home's estimated total economic impact (up through the year 2010) would be $4.5 billion in electronic sales.

TABLE 4: EVIDENCE OF BROADBAND'S NETWORK EFFECT: CONSUMER ELECTRONICS SALES DRIVEN BY FTTH

Consumer Electronic	% Sales Driven	Average Price	Total
HD televisions	15%	$1,400	$210
Wireless networking equipment	10%	$200	$20
Computers	6%	$1,000	$60
In-home wiring	4%	$2,000	$80
Videoconferencing cameras	1%	$50	$0.50
Total Average Per User			**$370.50**

to develop high-end products alongside companies, next-generation broadband extends the development environment to end-users. For example, the success of the game The World of Warcraft is due in part to gamers developing "worlds" within the game in partnership with the company. Overall, unfortunately, the data-intensivity of business collaboration tools (suffocated by bandwidth constraints) has meant that a lack of broadband bandwidth has slowed their introduction in business settings.

Other Business Applications

South Korea is developing commercial applications that leverage its high-speed broadband network. There, citizens who do not wish to use a credit card do not need online payment services to shop on the Internet. The country's banking system installed a real-time direct settlement capability directly on the country's networking infrastructure. Today, about 50 percent of all bank transactions go through the online channel, and another 30 percent take place through ATMs or telebanking using the same payment system.[106] As Chong ho Yoon, Head of Consumer Transactional Banking at Standard Chartered First Bank Korea Ltd., explains, "Because of the speed of the network—much of it 100 Mbps fiber optic—any banking Web site in Korea is rich in graphics and content. But the real-time transfer capabilities are the big thing. It eliminates the need for payment services like you have in America."[107]

POLICY IMPLICATIONS

While the primary purpose of this paper has been to highlight the innovative applications made possible by next-generation broadband and explain how they will benefit consumers, society, and businesses, there are several policy implications to consider in driving to deploy next-generation broadband networks in the United States. The first is that proactive policy intervention is justified due to the positive network externalities broadband Internet bestows. Second, communities seeking faster networks should if possible embrace public-private private partnerships with existing providers and not subsidize expensive "overbuilding" projects when there is already an existing network in the community that can in almost all cases be upgraded to faster speeds more cheaply than building an entirely new network. In this sense it is far more cost effective to work with those providers to expand coverage than to subsidize a redundant third (or fourth) pipe to a community. Third, policymakers should make adequate spectrum available to support next generation wireless innovation.

While left to their own devices markets will eventually deliver ubiquitous next-generation broadband service, because of significant externality effects the market will get there far more slowly than it would if supported by a proactive national broadband policy. Because broadband exhibits positive network externalities—the benefits from broadband adoption accrue not just to individual consumers, but to other broadband users and society as a whole—the social returns from investing in faster broadband exceed the private return to companies and consumers.[108] As a result, market forces alone will not deliver the societally-optimal level of next-generation broadband, and therefore proactive public policies—including a national broadband strategy—are needed to maximize overall society welfare.

Because broadband exhibits positive network externalities—the benefits from broadband adoption accrue not just to individual consumers, but to other broadband users and society as a whole—the social returns from investing in faster broadband exceed the private return to companies and consumers.

While next generation broadband exhibits several other kinds of externalities—including competitiveness externalities, regional externalities, and "prosumer" investment externalities—network externalities are perhaps the most important because of the new products and services broadband enables to emerge. There are two kinds of network externalities from broadband, direct and indirect. Direct externalities relate to subscribership, notably the fact that a network becomes more valuable to all users as additional users are added to the network.

Indirect network externalities relate to next-generation broadband's effect on applications and content that require broadband transport to work effectively. One reason why next-generation broadband take-up is not higher is because data-rich applications that could be accessed over broadband have not developed faster. Why develop a high-bandwidth intensive application like downloadable TV shows, telepresence, or telemedicine when few people would be able to access them at the needed speeds? More data-intensive applications would make high-speed broadband more valuable, while more high-speed broadband subscribers would make data-intensive applications more commercially viable. For example, YouTube succeeded where Broadcast.com failed. Broadcast.com had the exact same concept and business model as YouTube, but it failed in the late 1990s because of an insufficient critical mass of high-speed broadband users to both upload and download content. It has only been in the last several years that there has been sufficient high-speed broadband for YouTube's business model to become viable.[109]

By aggressively supporting the deployment of next-generation broadband networks, governments have short-circuited the system interdependency paradox, and casued the future to arrive faster by fostering an environment where next-generation Web applications can be developed without concerns that customers would lack the requisite infrastructure to take advantage of them.

In other words, policy is justified to address the "chicken-or-egg" conundrum which slows deployment of next-generation broadband: consumers may be reticent to buy next-generation broadband service because there are not enough compelling applications that leverage high-speed networks; at the same time, would-be developers of those applications are hesitant to develop them if they fear an insufficient market exists. By aggressively supporting the deployment of next-generation broadband networks, the governments of Japan, South Korea, Sweden, and others have short-circuited this paradox, and caused the future to arrive faster by fostering an environment where the development of next-generation Web applications could occur without concerns that customers would lack the requisite infrastructure to take advantage of them.

Many nations, including Japan, South Korea, and Sweden, have spurred the deployment of faster networks through direct subsidies, including grants, low-interest loans, and accelerated depreciation on network investments. For example, the Japanese government allowed incumbent provider NTT to rapidly write off the cost of its new fiber broadband networks.[110] The South Korean government did the same for fiber investments in South Korea.[111] Austria and Sweden allowed individual consumers to deduct broadband expenses from their taxes.[112] Canada recently increased by fifty percent its tax incentives for investments in broadband, Internet, and other data network infrastructure equipment.[113]

To spur more ubiquitous high-speed broadband deployment, Congress should do the same for providers in the United States. The government should also allow companies investing in broadband networks to expense investments in new high-speed broadband networks (capable of delivering considerably faster speeds than today's average DSL or cable networks) in the first year. Currently, companies in the United States must depreciate telecommunications network investments over a period of fifteen years.[114] Allowing companies to deduct the investment in the first year reduces the costs of making these investments and spurs faster deployment of higher speed networks.[115]

The question of whether telecommunications—and in particular broadband—is like banking, airlines, and trucking, or more like municipal water, electricity, and gas service (in other words, whether broadband is more like a natural monopoly or a service provided in highly competitive markets) has been at the center of debates over telecommunications for many years, and should be at the center of the broadband debate as well.

In this regard, the bias toward competition in today's broadband debate is misguided. It ignores the fact that there are elements of broadband infrastructure that have natural monopoly aspects, much like water, gas, and sewer pipes. For example, during the height of the electricity deregulation movement in the 1990s, few advocates proposed de-regulating the local electricity delivery network because that part of the system was rightly seen as a natural monopoly.[116]

Yet, for some reason, that basic insight has not translated to broadband networks. One reason is that many, particularly those on the left, look at network costs as the responsibility of corporations—if competition drives down revenues, it is no one's problem but their own. At least consumers then benefit from the heightened competition. The situation would be no different, however, if all telecommunications providers were municipal owned. In either case, providers who lose market share from increased competition while having to support fixed cost networks have to raise prices to avoid losing money. If providers are forced to amortize the fixed costs of their networks over significantly fewer customers, prices will increase even if profits are squeezed and efficiencies maximized.

This is not to suggest that competition does not bring benefits, such as increased consumer choice, as well as pressure to innovate and cut costs. However, it is critical to realize that in the case of last-mile infrastructure, multiple networks also bring costs. The issue, then, becomes one of balancing the efficiency of fewer networks with the competitive benefits of more networks. What public policy should *not* do is intentionally tilt the playing field toward a third (or "nth") pipe through special subsidies, including municipal provision.[117] Municipal provision of broadband networks should be a last resort, not a first. If private sector providers are unwilling to extend and upgrade networks, even after they are offered incentives to do so, then municipal provision may make sense. But public subsidies of a third (or fourth) pipe simply raise the overall costs of broadband infrastructure in an area and these costs are borne by all customers of existing providers, even if they do not reside in the area with additional providers. Therefore, at best, any national policy should be neutral toward competition. It should seek to remove any unnecessary barriers to competition—such as restrictions and high prices placed on pole access and trenching by local governments—but it should not tilt the playing field to actively promote more competition.

Although public policy should not proactively subsidize the deployment of additional networks, conversely it should not erect or maintain barriers to the emergence in the market of additional networks. With respect to spectrum, this means freeing up inefficiently used or underutilized spectrum, including spectrum in so-called "white spaces," while letting the marketplace (with the exception of first responder uses) decide on its highest and best use.[118]

With regard to wireless spectrum, much of the spectrum in the 700 MHz range will be used for IP data transmission. Given that there are areas that cannot get either DSL or cable modem service, developing a "first" pipe in these locations is important. In this situation, it appears that fixed wireless may be the most cost-effective technology, so it's important to have public policies, particularly with respect to spectrum, to help enable this. But it would be just as wrong to limit such spectrum from being used for broadband services as it would be to mandate its use for broadband. Likewise, with respect to broadband over power lines, the policy should be to remove unnecessary regulatory obstacles to deployment. But policy should not tilt the playing field to promote a particular technology.

CONCLUSION

The history of information technology is one of continuously overrating the adequacy of current CPU processing speeds, disk storage capacity, and network transmission speeds and thus underestimating how technological innovation and new applications drive consumer demand for ever-increasing speeds and greater capacity. There is no reason to believe that network transmission speeds of 5 Mbps will not seem every bit as antiquated to us in five to ten years as 56 Kbps seems to us today.

Deploying next-generation broadband networks will have profoundly positive benefits for consumers, businesses, academic institutions, and society in general. Next-generation broadband represents a core infrastructure that will be increasingly woven into the fabric of life for all citizens, impacting on a daily basis their ability to telework or actually operate their own businesses from home, interact with friends and family, receive high-quality entertainment, interface with their government, and manage their family's health and household activities. Households will require substantial broadband bandwidth to accommodate demand from multiple family members—and autonomous appliances in the home—simultaneously running a number of bandwidth-hungry Internet applications.

Deploying next-generation broadband networks will also create U.S. employment. Deploying next-generation broadband to 80 percent of U.S. households that currently lack it would create approximately two million new or retained direct and indirect jobs in the United States.

As other countries race towards average download speeds in excess of 50 Mbps, the time has come to develop a comprehensive strategy for the deployment of a ubiquitous next-generation broadband network in the United States.

ENDNOTES

1. Mr. Olsen's quote is frequently cited as having been said in a speech he gave to the Convention of the World Future Society in 1977. Fred Shapiro, the editor of "The Yale Book of Quotations," who seeks the original source of several well-known computer-related sayings and statements, has been unable to find contemporaneous documentation of this. Mr. Shapiro notes the Olsen quote may be apocryphal.

2. This report describes next-generation broadband networks as having a minimum upload speed of 10 Mbps because this upload speed should be normally achievable using fiber to the home (FTTH), DOCSIS 3.0, or fiber to the node (FTTN) solutions. Fiber to the home, using gigabit passive optical network (GPON) architecture, is capable of 2,400 Mbps downstream and 1,200 Mbps upstream shared between a maximum of 32 homes, though more likely 7 to 13 homes populated. That means FTTH GPON has a worst-case minimum capacity of 185 Mbps downstream and 92 Mbps upstream per home. Based on an average peak-hour duty cycle of 10 percent utilization per home, an effective peak hour capacity of 1850/920 Mbps downstream/upstream per home is achievable and this is the realistic minimum performance. DOCSIS 3.0 cable broadband technology, using four 6-MHz channels for downstream and four 4 MHz channel for upstream, is capable of 160 Mbps downstream and 120 Mbps upstream shared between 200 to 300 homes. That means a worst-case minimum capacity of 0.64 Mbps downstream and 0.48 Mbps upstream is achievable. Based on an average peak-hour duty cycle of 10 percent utilization per home, an effective capacity of 6.4 Mbps downstream and 4.8 Mbps upstream is achievable. With an average of 2 percent utilization per home, the effective average capacity per home is 32 Mbps downstream and 24 Mbps upstream and because most users do not opt for the highest-performing services, a few premium users can be offered 60 or even 100 Mbps service. However, as consumers begin to watch television through on-demand Internet video streaming services, average home utilization could jump to 20 percent, meaning DOCSIS 3.0 capacity will begin to drop severely unless more channels are allocated. Allocating more channels is difficult as it would require cable companies to give up revenue-generating on-demand cable TV channels or it would require cable companies to undergo an expensive transformation to digital switched video architecture. Fiber to the node, operating within 1,000 meters of the home using two phone lines (channel bonding), can achieve 50 Mbps downstream and 10 Mbps upstream of dedicated capacity, rivaling the minimum performance of earlier FTTH systems. FTTN on average does not perform as well as either FTTH or DOCSIS 3.0 because it has no ability to dynamically shift burst capacity to the active homes. However, FTTN performance remains the same no matter how heavy the neighborhood utilization becomes, meaning it can handle the looming transition to on-demand Internet video streaming.

3. Fiber to the Node is included in this list of next-generation broadband technologies because dual channel FTTN can hit 50 Mbps of dedicated capacity.

4. Communications Workers of America, "Speed Matters: A Report on Internet Speeds in All Fifty States," (Washington, D.C.: Communications Workers of America, August 2008) < www.speedmatters.org/document-library/sourcematerials/cwa_report_on_internet_speeds_2008.pdf> (accessed January 12, 2009).

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ABOUT THE AUTHORS

Dr. Robert D. Atkinson is President of the Information Technology and Innovation Foundation, a Washington, DC-based technology policy think tank. He is also author of the *The Past and Future of America's Economy: Long Waves of Innovation that Power Cycles of Growth* (Edward Elgar, 2005).

Stephen Ezell is a Senior Analyst with ITIF, with a focus on international information technology competitiveness and national innovation policies. Mr. Ezell comes to ITIF from Peer Insight, an innovation research and consulting firm he co-founded in 2003 to study the practice of innovation in service industries. At Peer Insight, Mr. Ezell co-founded the Global Service Innovation Consortium, published eight research papers on service innovation, and researched national service innovation policies being implemented by governments worldwide.

Daniel Castro is a Senior Analyst with ITIF. His research interests include technology policy, security, and privacy. Castro has an MS in information security technology and management from Carnegie Mellon University.

George Ou is a Senior Analyst with ITIF and works out of Silicon Valley. He recently served two years as Technical Director and Editor at Large for TechRepublic and ZDNet doing in-depth coverage on IT and technology topics. Before journalism, he worked as an IT professional who designed and built wired network, wireless network, Internet, storage, security, and server infrastructure for various Fortune 100 companies.

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ITIF | 1250 I St. N.W. | Suite 200 | Washington, DC 20005