# The Spectrum Imperative:

# Mobile Broadband Spectrum and its Impacts for U.S. Consumers and the Economy

# An Engineering Analysis

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http://www.rysavy.com

# Table of Contents

## Executive Summary

The purpose of this report is to analyze, from an engineering perspective, the consequences of failing to make new spectrum available to consumers, the economy and the wireless sector. This report discusses how spectrum relates to capacity, how different types of applications and devices can consume available capacity, and the effects of insufficient spectrum.

For consumers, these effects include unreliable service and performance and potentially higher connectivity costs—a development that would place an essential modern service out of the reach of many Americans, including those who stand to gain the most from all that mobile connectivity has to offer. To the extent that service providers respond to capacity constraints by limiting demand through usage caps and significantly higher pricing, consumers' ability to access the Internet may be limited or come at a higher cost. These effects will particularly harm those, including many minorities and low-income Americans, who primarily rely on their mobile devices to access the Internet. This in turn rolls back the promise of mobile connectivity and innovation, denying access to critical services and opportunities.

The market consequence of such an environment will be less incentive for businesses to invest in new applications, services and devices because performance, and thus customer enthusiasm, will likely be subpar. This jeopardizes the 2.4 million American jobs currently supported by mobile innovation. And, the ultimate price of this downward spiral is a loss of U.S. leadership in the global innovation economy.

## Introduction

U.S. mobile innovation continues to surge forward, fueled by a combination of faster networks, powerful next-generation wireless devices, including smartphones and tablets, and innovative applications that take increasing advantage of our constant state of connectivity. Lifestyles are enhanced and work is more productive, as the full and growing value of the Internet is increasingly ever-present and accessible in the palms of our hands.

Compelling data already exists to illustrate the important role that mobile technology plays in powering our innovation economy and empowering American consumers and businesses. And, we see clear evidence today that wireless broadband is helping to bridge the digital divide, with minority and lower-income Americans increasingly turning to mobile services as their primary connection to the Internet.

The number of U.S. consumers with broadband access on their mobile device has risen from three million in 2006 to 73 million in 2008.[1] As early as 2014, more people may go online via mobile devices than PCs.[2] And, within this decade an estimated 10 billion devices—from the medical tablet at the

[1] Source: "US Broadband Ranking: Does it Matter?," *PC WORLD*, June 5, 2009.

[2] Source: Mobile Internet Report, *Morgan Stanley*, December 2009.

hospital, to the textbook in your child's school to the thermostat in your home—will be perpetually connected thanks to ubiquitous wireless broadband technology.[3]

Mobile broadband is providing new business opportunities across vertical markets, including the automotive, banking, consumer electronics, transportation, and utilities industries. Already, there are vehicle accident recovery applications, mobile payment and online banking applications, remote health monitoring devices, smart utility meters, refrigerators, picture frames, pill bottle caps, traffic lights, and parking meters that use mobile technology. Mobile connectivity is poised to transform virtually every sector of the U.S. economy—from commerce to health care, education to energy efficiency. This mobility-enhanced world, however, depends on a constant, reliable flow of bits between people, devices and the Internet. As mobile devices become more powerful, as device resolution increases, as users employ more applications and as connectivity increasingly is embedded in virtually every manner of machine, this flow of bits is increasing at a dramatic rate.

The amount of bandwidth available to each user depends on many factors. But one of the most critical is the amount of radio spectrum available. As FCC Chairman Julius Genachowski has stated, "the explosive demand for wireless innovation is testing the limits of a fundamental resource: spectrum. It is the oxygen of the wireless world — fueling every aspect of our mobile broadband ecosystem."[4]

Cisco recently reported that in 2010, global mobile data traffic grew 2.6 fold, nearly tripling for the third year in a row.[5] Within three to four years, Rysavy Research estimates that our nation's appetite for wireless consumption could outstrip existing capacity. While carriers will attempt to alleviate congestion in the short-term by offloading traffic using femtocells and picocells, mobile innovation will falter without access to the substantial additional spectrum that American consumers and businesses will soon need, and the consequences of inaction for the nation are unacceptable.

Recognizing the urgency of the situation, the Obama Administration and the FCC plan to make 300 MHz of new spectrum available over the next 5 years and 500 MHz over the next 10 years,[6] almost double the 547 MHz of spectrum currently licensed for mobile broadband.[7]

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[3] Source: *Id*.

[4] Source: *The Hill*, "Spectrum: oxygen of wireless world," Julius Genachowski, September 24, 2009. http://thehill.com/special-reports/technology-september-2009/60265-spectrum-oxygen-of-wireless-world.

[5] Source: *Cisco*, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2010-2015," February 1, 2011.

[6] Source: *FCC,* "Connecting America, The National Broadband Plan," March 2010; The White House, Presidential Memorandum: Unleashing the Wireless Broadband Revolution (June 28, 2010). http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution.

As consumers race to embrace all that wireless broadband connectivity has to offer and U.S. mobile innovation continues to advance at an astounding pace, there is a clear and compelling national interest in ensuring adequate spectrum is available to continue this progress. Unfortunately, we cannot simply flip a switch and make more broadband spectrum available; it typically takes several years for spectrum to be repurposed and released into the marketplace.[8] And the clock is ticking with rising demand rapidly closing the gap with existing supply. The consequences of inaction are severe, widespread and wholly negative for consumers and the U.S. economy. Equally true, these substantial adverse impacts can be averted with bold and timely leadership today.

## Spectrum and Capacity

To understand why additional spectrum is so crucial, one must understand how spectrum relates to capacity and how quickly users can consume what is available to them. This is especially true for consumers who live in population-dense urban environments, where the upper limits of current spectrum capacity are likely to first be reached and tested.

Modern wireless networks are digital, meaning they communicate binary data. The amount of data that a radio channel can carry depends on the width of the radio channel, the modulation used, and how the data is encoded. Each wireless technology uses radio channels of certain width. For example, CDMA2000 (as used by Sprint and Verizon) radio channels are each 1.25 megahertz (MHz) wide whereas High Speed Packet Access (HSPA as used by AT&T and T-Mobile) radio channels are 5 MHz wide. Long Term Evolution (LTE) radio channels can range from 1.4 MHz in width to 20 MHz.

To derive capacity, we must look at this width of the radio channel and consider the average spectral efficiency of the technology in typical deployments. For this purpose, spectral efficiency is defined as how many bits per second a given amount of spectrum can carry and is measured as bits per second per Hz of spectrum. HSPA in typical deployments has a downlink (base station to mobile user) spectral efficiency value of about 1.0 bps/Hz.[9] This means a 5 MHz HSPA radio channel has an aggregate downlink capacity of 5 million Hz multiplied by 1.0 bps/Hz, which equates to 5.0 million bits per second, or 5.0 Mbps.[10] This is the total capacity in a cell sector[11] for that radio channel, a capacity that must be

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[7] Source: *FCC*, "Connecting America, The National Broadband Plan," March 2010, at 85, Exhibit 5-F.

[8] Source: *Id*. at 70, Exhibit 5-C.

[9] For a detailed discussion of spectral efficiency and spectral efficiency values of different technologies, refer to page 51 of Rysavy Research, "Transition to 4G," September, 2010, http://www.rysavy.com/Articles/2010_09_HSPA_LTE_Advanced.pdf. 1.0 bps/Hz assumes a high level of technology enhancement and most existing HSPA networks operate at spectral efficiencies only half or two thirds of this value.

[10] In general, modern wireless technologies operate more efficiently with wider radio channels. This effect is not taken into account in the calculations of capacity in this paper.

shared by multiple users. The 5 MHz radio channel actually translates to 10 MHz of spectrum used since there is a separate 5 MHz radio channel for the uplink.

LTE has a higher spectral efficiency and can operate in wider radio channels. For example, an LTE radio channel of 10 MHz has a downlink spectral efficiency value of 1.5 bps/Hz and would thus have a downlink capacity of 15 Mbps. There is also an uplink channel of 10 MHz with a typical spectral efficiency value of .65 bps/Hz, equating to an uplink capacity of 6.5 Mbps. Together, the LTE downlink and uplink channels consume 20 MHz of spectrum.

The question then is how much total capacity an operator actually has for mobile broadband. This depends on how much spectrum the operator has and the distribution of cell sites. More cell sites mean fewer people have to share the radio channel since that radio channel is servicing a smaller area. But there are limits to how many cell sites can be practically deployed, with most of the easiest-to-deploy locations already in use.

In addition, when evaluating the total capacity, the spectrum an operator needs to support voice and legacy services, such as 2G, will reduce the total amount of spectrum available for mobile broadband.[12] Rysavy Research estimates that for a typical operator, roughly 20 MHz is needed for voice service in any coverage area. Subtracting this spectrum requirement for voice from total typical amounts of spectrum that operators have, mobile-broadband technologies such as HSPA or LTE could be deployed to support mobile broadband service in about 30 to 80 MHz of spectrum in a coverage area, assuming a typical upper limit of about 100 MHz of total spectrum available to operators in any market. Six channels of HSPA, each 5 MHz wide (using separate channels for the downlink and uplink), would require a total of 60 MHz. Alternatively, three 10 MHz LTE channels would require 60 MHz and four 10 MHz LTE channels would consume 80 MHz. Note, however, that an operator only deploys as many radio carriers as needed to meet capacity requirements for that cell sector.

Table 1 shows how cell sector capacity relates to different technology configurations, including the number of radio carriers that might be deployed. For example, an HSPA operator that has deployed 2 HSPA radio carriers in a cell site would consume 20 MHz of spectrum and would have 10 Mbps of aggregate downlink capacity in each sector and 5 Mbps of uplink capacity in each sector. Note that other currently deployed broadband technologies such as EV-DO and WiMAX have a comparable spectral efficiency to HSPA.

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[11] Most cell sites are divided into three sectors, so each cell sector (pie-slice shape) represents one third of the coverage of a cell tower.

[12] For example, operators with HSPA, a 3G technology, also need some spectrum available for GSM, a 2G technology.

**Table 1: Spectrum Used and Sector Capacity for Different Configurations**

| Technology | Radio Carrier Width (MHz) | Carriers | Total Spectrum Used (MHz) | Downlink Spectral Efficiency | Downlink Sector Capacity (Mbps) | Uplink Spectral Efficiency | Uplink Sector Capacity (Mbps) |
|---|---|---|---|---|---|---|---|
| HSPA | 5 | 1 | 10 | 1.0 | 5 | 0.5 | 3 |
| | | 2 | 20 | | 10 | | 5 |
| | | 3 | 30 | | 15 | | 8 |
| | | 4 | 40 | | 20 | | 10 |
| | | 5 | 50 | | 25 | | 13 |
| | | 6 | 60 | | 30 | | 15 |
| LTE | 10 | 1 | 20 | 1.5 | 15 | 0.65 | 7 |
| | | 2 | 40 | | 30 | | 13 |
| | | 3 | 60 | | 45 | | 20 |
| | | 4 | 80 | | 60 | | 26 |

Note: LTE can be deployed in radio channels ranging from 1.4 to 20 MHz. 10 MHz is a typical initial configuration for some operators.

Now let's examine market conditions with respect to spectrum in two U.S. cities, Philadelphia and San Diego. In those two markets, there are at least five wireless carriers with 40 MHz or more of spectrum, according to the FCC's Spectrum Dashboard.[13]

In Philadelphia and San Diego, AT&T and T-Mobile offer GSM and HSPA service.[14] Clearwire offers a 4G WiMax mobile service in Philadelphia and has plans to launch 4G service in San Diego this year.[15] In Philadelphia, Sprint Nextel, through its relationship with Clearwire, has a 3G CDMA EV-DO and WiMAX service offering and offers 3G service in San Diego.[16] Verizon launched its 4G LTE service this past December and also offers CDMA EV-DO service in both markets.[17]

Using the mobile wireless penetration rate determined by the FCC in its latest competition report for the Philadelphia and San Diego Economic Areas against the U.S. Census Bureau's latest population data, the

[13] The Spectrum Dashboard may not fully reflect all of the spectrum and ownership elements in the two markets but provides a useful proxy for this analysis. Source: *FCC*, "Spectrum Dashboard," http://reboot.fcc.gov/spectrumdashboard/searchMap.seam (last visited on Mar. 9, 2011); *Morgan Stanley*, "The Mobile Internet Report," 2009.

[14] Source: AT&T, http://www.wireless.att.com/learn/why/network/index.jsp?wtSlotClick=1-00245D-0-1&WT.svl=calltoaction (last visited Jan. 27, 2011); T-Mobile, http://t-mobile-coverage.t-mobile.com/4g-wireless-technology?uid=Coverage_2 (last visited Jan. 27, 2011).

[15] Source: Clearwire, http://www.clear.com/coverage (last visited Jan. 27, 2011); Craig Howie, "Tech Trends: Clear Mobile Device Lets You Take 4G (or 3G) Internet Access with You," *L.A. TIMES*, Nov. 29, 2010, http://articles.latimes.com/2010/nov/29/business/la-fi-clear-4g-20101130.

[16] Source: Sprint Nextel, http://coverage.sprintpcs.com/IMPACT.jsp?INTNAV=ATG:HE:Cov (last visited Jan. 27, 2011).

[17] Source: Verizon Wireless, "Verizon Wireless Launches The World's Largest 4G LTE Wireless Network On Dec. 5" (Dec. 4, 2010), http://news.vzw.com/news/2010/12/pr2010-11-30a.html; Verizon Wireless, http://aboutus.vzw.com/bestnetwork/network_facts.html (last visited Jan. 27, 2011).

estimated number of mobile wireless subscribers in Philadelphia is about 1.45 million and in San Diego, about 1.3 million.[18] There are an estimated 1,450 cell sites in Philadelphia and 1,200 sites in San Diego, with each site covering about 1,100 subscribers.[19] With three sectors commonly used at cell sites, we will assume there are about 360 subscribers per cell sector. In Philadelphia, there are an estimated 660,000 adults that access the Internet wirelessly and more than 570,000 in San Diego.[20]

The demographic makeup of these two cities is as follows:

- Of the more than 1.5 million residents in Philadelphia, 53.2% are female; 43.5% white; 42.7% black or African American; 11% Hispanic or Latino; 5.5% Asian; 76% are 18 years and older and 12.7% are 65 years and older.[21] The median household income in Philadelphia is $36,669, and the percentage of families and individuals that are below the poverty level are 19.2% and 24.2%, respectively.

- Of San Diego's 1.3 million residents, 49.7% are female; 66.7% white; 6.8% black or African American; 27.3% Hispanic or Latino; 14.8% Asian; 77.6% are 18 years and older and 10.7% are 65 years and older.[22] The median household income is $61,962, and the percentage of families and individuals that are below the poverty level are 8.8% and 13.1%, respectively.

[18] Source: *Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services*, WT Docket No. 09-66, Fourteenth Report, 25 FCC Rcd 11407, 11644 Table C-3 (2010); US Census Bureau, http://factfinder.census.gov (search using "Philadelphia" and "San Diego") (last visited Jan. 27, 2011). Note we are using estimates based on generally available numbers.

[19] Source: Dr. Robert F. Roche & Lesley O'Neill, CTIA, "CTIA's Wireless Industry Indices," 161, November 2010, at 161 (providing mid-year 2010 results and calculating 1,111 subscribers per cell site). Cell site estimates based on the estimated number of subscribers in Philadelphia and San Diego against the average number of subscribers per cell site. Source: *Id*. at 8.

[20] Estimates based on percentage of American adults that have a wireless connection and use a laptop or cell phone to access the Internet as determined by the Pew Internet and American Life Project (Pew Internet), i.e., 57%, compared to the estimated population of people in Philadelphia and San Diego that are 18 years or older. Source: Susannah Fox, "Mobile Health 2010," Pew Internet (Oct. 19, 2010), http://www.pewinternet.org/Reports/2010/Mobile-Health-2010.aspx; U.S. Census Bureau, http://factfinder.census.gov (search using "Philadelphia" and "San Diego").

[21] Source: US Census Bureau, http://factfinder.census.gov (search using "Philadelphia") (last visited Jan. 27, 2011).

[22] Source: US Census Bureau, http://factfinder.census.gov (search using "San Diego") (last visited Jan. 27, 2011).

According to a recent report released by the Pew Research Center's Internet & American Life Project, minority groups are the leading demographic segment to adopt mobile services. Pew found that 63% of Hispanics and 64% of African Americans access the Internet wirelessly, more than whites at 57%.[23] Lower-income people, independent of race, also are increasingly likely to access the Internet wirelessly, according to Pew.[24] A National Health Interview Survey showed more than 26% of homes are wireless-only and do not have a landline telephone, with adults living at or near poverty more likely than higher-income adults to live in wireless-only households.[25] Moreover, Hispanic adults at 34.7% and black adults at 28.5% were more likely than white adults at 22.7% to be living in a wireless-only household.[26] Assuming these trends hold true, there is a higher percentage of residents in Philadelphia, and a higher percentage of Hispanics and Latinos living in San Diego, who rely on mobile broadband as their primary connection than the national average due to the demographics of these markets.[27]

As we will see in the next section, a relatively small percentage of the subscribers in Philadelphia and San Diego, and/or seemingly small shifts in the kinds of devices and/or applications commonly used, can easily overwhelm the available capacity of a given cell site antenna sector based on currently available spectrum.

## Application and User Demands

In markets like Philadelphia and San Diego and around the country, ever more sophisticated applications present fast-growing demands on the network. Whereas e-mail and web browsing of relatively static content present a minimal load, streaming applications, such as the Pandora music or Netflix video applications, can consume large amounts of available bandwidth because this more data-intensive content has to be continually and reliably delivered. Over the last four years, consumers have increasingly come to rely on their wireless broadband devices for high-bandwidth applications. Even a seemingly subtle shift in time and consumption habits—or even upgrading a device—can drive up data usage by several orders of magnitude.

[23] Source: Aaron Smith, "Mobile Access 2010," *Pew Research Center's Internet & American Life Project*, 3, 9 (July 7, 2010), http://www.pewinternet.org/Reports/2010/Mobile-Access-2010.aspx ("Mobile Access 2010).

[24] Source: Mobile Access 2010 at 9.

[25] Source: Stephen J. Blumberg and Julian V. Luke, "Wireless Substitution: Early Release of Estimates from the National Health Interview Survey, January-June 2010," National Center for Health Statistics, *CDC*, at 1, 3, Dec. 21, 2010, http://www.cdc.gov/nchs/data/nhis/earlyrelease/wireless201012.htm.

[26] Source: *Id*.

[27] The population percentage of blacks and African Americans and Hispanics and Latinos for the entire U.S. is 12.1% and 15.1%, respectively, compared to 42.7% and 11% in Philadelphia and 6.8% and 27.3% in San Diego. Families and individuals below the poverty level for the entire U.S. are 9.9% and 13.5%, respectively, compared to 19.2% and 24.2% in Philadelphia. Source: US Census Bureau, http://factfinder.census.gov (search using "Philadelphia").

Table 2 shows the typical throughput requirements of various streaming applications that might include increasingly popular applications for telemedicine, education, social networking, entertainment, field service, business collaboration, and so forth. The table includes the amount of data each application consumes per hour measured in megabytes, and how many gigabytes each individual application would consume in a 30-day month based on daily consumption amounts of .5 hours, 1 hour, 2 hours and 4 hours.

**Table 2: Data Consumption of Typical Applications**

| Application | Throughput (Mbps) | MByte/hour | Hrs./day | GB/month |
|---|---|---|---|---|
| Audio or music | 0.1 | 58 | 0.5 | 0.9 |
| | | | 1.0 | 1.7 |
| | | | 2.0 | 3.5 |
| | | | 4.0 | 6.9 |
| Small screen video | 0.2 | 90 | 0.5 | 1.4 |
| | | | 1.0 | 2.7 |
| | | | 2.0 | 5.4 |
| | | | 4.0 | 10.8 |
| Medium definition video | 1.0 | 450 | 0.5 | 6.8 |
| | | | 1.0 | 13.5 |
| | | | 2.0 | 27.0 |
| | | | 4.0 | 54.0 |
| Higher definition video | 2.0 | 900 | 0.5 | 13.5 |
| | | | 1.0 | 27.0 |
| | | | 2.0 | 54.0 |
| | | | 4.0 | 108.0 |
| High definition, full screen video | 4.0 | 1800 | 0.5 | 27.0 |
| | | | 1.0 | 54.0 |
| | | | 2.0 | 108.0 |
| | | | 4.0 | 216.0 |

**Video applications: telemedicine, education, social networking, entertainment.**

The table demonstrates how relatively discrete use patterns can quickly result in large monthly data usage totals. For example, an hour of audio a day adds up to 1.7 gigabytes (GB) over a month. And, 30 minutes a day of medium-definition video consumes 6.8 GB.

Actual amounts of data being consumed in the marketplace validate these estimates. Clearwire indicated in 2010 that subscribers were already consuming 7 GB per month.[28] Teliasonera in Finland, the

[28] Source: Fierce Wireless, "Clearwire upgrades network management system to better throttle speeds," October 11, 2010, http://www.fiercewireless.com/story/clearwire-says-it-will-throttle-data-speeds-during-high-usage/2010-10-11.

first LTE operator, reported LTE data-card subscribers using 14 GB to 15 GB per month, three times their 3G data-card users.[29] This monthly amount is consistent with average fixed broadband consumption of 14.9 GB per month, as reported by Cisco.[30] If mobile broadband networks existed in isolation, operators might be able to manage performance expectations. But wireline networks with much higher capacities often set user expectations, resulting in users frequently wishing to do the same things over mobile networks as they do over wireline networks. With policymakers working to extend broadband to a larger percentage of the population while at the same time promoting broadband competition, it is crucial that mobile broadband be a competitive and viable alternative. This is particularly important if mobile broadband is to play an important role in sectors such as healthcare, education and energy.

Data usage across all device types is growing quickly. For instance, Rysavy Research projects smartphone data consumption increasing from about 0.3 GB per month to almost 10 times this amount within 5 years, as shown in Figure 1.[31]

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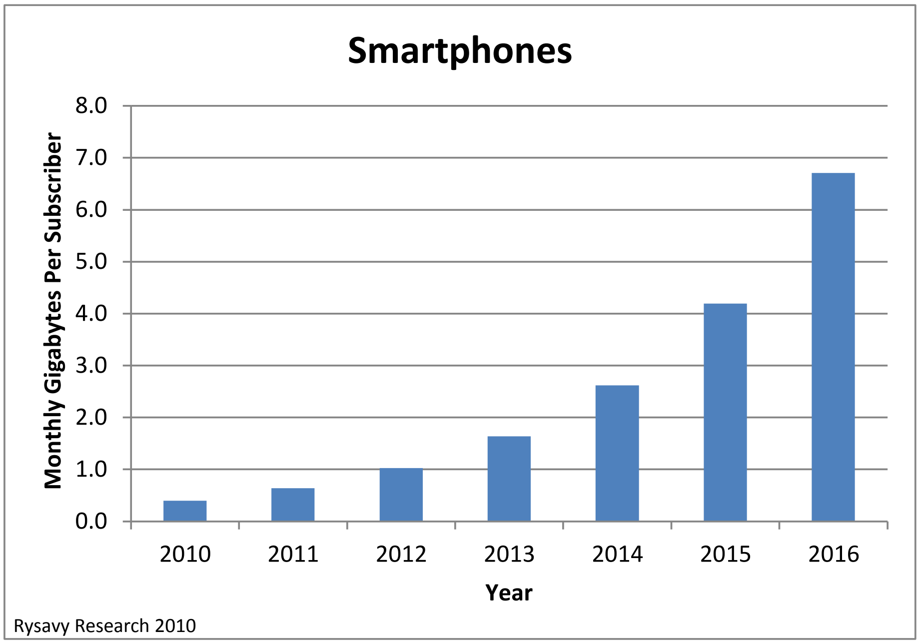
[29] Source: Gigaom, "Operator Says LTE Subscribers Using 15 GB Per Month!," November 15, 2010, http://gigaom.com/2010/11/15/wireless-vs-wired-broadband/.

[30] Source: Cisco, "Cisco Visual Networking Index: Usage," October 25, 2010, http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/Cisco_VNI_Usage_WP.html.

[31] Source: Rysavy Research, "Mobile Broadband Capacity Constraints and the Need for Optimization," February 24, 2010, http://www.rysavy.com/Articles/2010_02_Rysavy_Mobile_Broadband_Capacity_Constraints.pdf.

Figure 1: Smartphone Data Projection




Consumers are increasingly using mobile for telemedicine, distance learning, and social networking. In addition, there is a growing demand for mobile business applications by enterprise users. With the expected rapid growth in usage of new, data-heavy services and applications, it is critical to make more spectrum commercially available to accommodate growing consumer demand. It is important to note that emerging wireless applications such as machine-to-machine communications and tablet computing could result in far greater demand for capacity than amounts anticipated by simply extrapolations of current usages.

A variety of factors are fueling continued growth in usage, including: faster networks, more network-enabled devices, increasing computing speeds that enable more complex data-consuming applications, gaming, larger displays, and higher screen resolution.

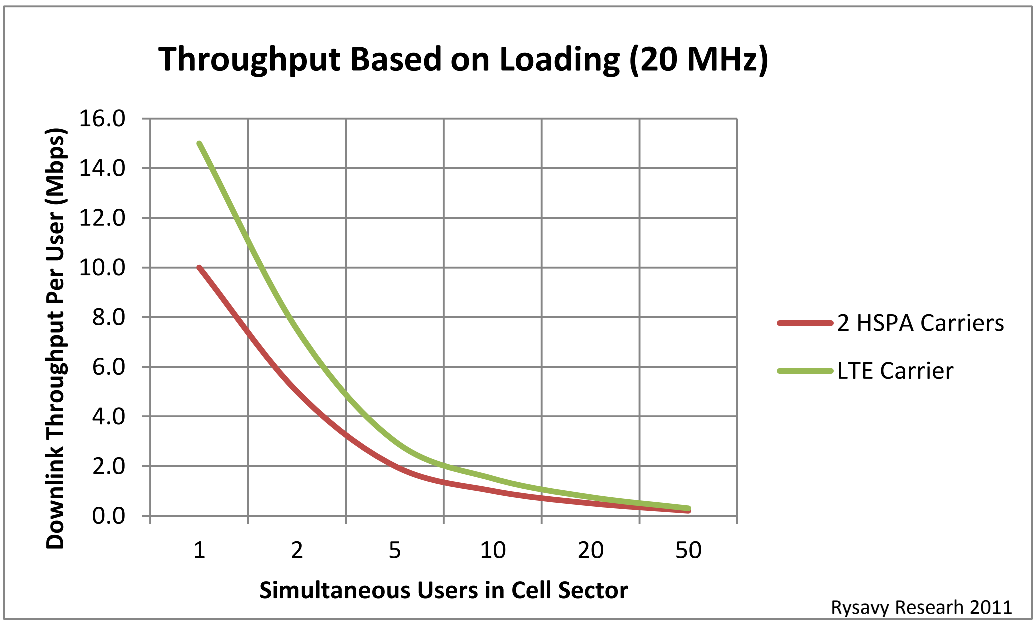
Taking just one of these factors, screen resolution, Table 3 shows how increasing resolution results in higher video encoding rates and increased broadband capacity consumption. Assuming typical advanced video encoding and full-screen video, going from the iPhone 3 to iPhone 4 quadruples the video data consumption rate. The third row presents a high-definition stream for comparison. The point is that even though devices are relatively small, increasing video resolution forces them to consume larger amounts of data. Thus, even if a consumer's usage of mobile video stayed constant – which is highly unlikely – bandwidth demands would skyrocket simply because of the shift in screen resolution.

Table 3: Typical Video Usage Rate Based on Type of Device

| Device | Vertical | Horizontal | Megapixels | Typical Video Rate (Mbps) |
|---|---|---|---|---|
| iPhone 3 | 320 | 480 | 0.2 | 0.4 |
| iPhone 4 | 640 | 960 | 0.6 | 1.6 |
| 1080p HD | 1080 | 1920 | 2.1 | 5.4 |

To put these usage rates into a wireless-networking perspective, Figure 2 below takes the network capacities presented in Table 1 and shows what downlink throughput rates are available, based on the number of simultaneous users, assuming an operator is using 20 MHz for mobile broadband, e.g., Verizon uses 20 MHz for LTE.

Figure 2: Available Throughput Per User Based on Network Loading




The fact is that if users are engaged in 1 Mbps or 2 Mbps streams or downloads, it takes a relatively small number of users to consume sector capacity. For LTE, it takes only about eight users with a 2 Mbps stream to reach the 15 Mbps sector capacity that one operator may have deployed. As noted earlier in this report, there is an estimated average of about 360 subscribers per cell sector per operator. Denser cell sites in cities, like Philadelphia and San Diego, could have two or three times as many subscribers. To put this into perspective, cell-site spacing in an urban area could be 1,000 feet between cell sites, with each cell site covering about 10 city blocks. Since each site comprises three sectors, this means a sector has to cover about three city blocks. This sector capacity has to be shared across all the users in this area. Operators will augment capacity with additional radio channels, but doubling the amount of spectrum to 40 MHz using LTE would still only accommodate 16 simultaneous users consuming 2 Mbps streams.

Even if an operator with 100 MHz of total spectrum holdings had 80 MHz of spectrum allocated to LTE, this would still represent only about 60 Mbps of aggregate downlink capacity in a cell sector for those three city blocks, accommodating 30 simultaneous users consuming 2 Mbps streams in a given sector. However, unless more spectrum is made available, it is highly unlikely that even four providers could reach these spectrum holdings in a given market like Philadelphia or San Diego.

The FCC states that there is 547 MHz of spectrum currently licensed that can be used to provide mobile broadband.[32] In Philadelphia, this licensed spectrum is divided up among more than 20 different spectrum holders with no one entity holding 100 MHz.[33] Three major providers in Philadelphia have between 75 and 99 MHz and the next 4 have between 10 and 50 MHz. In San Diego, there are more than 30 spectrum holders.[34] The top four providers in San Diego have between 70 and 104 MHz; and the next two have between 30 and 40 MHz.[35] Unless more spectrum is made available, there would need to be significant consolidation in the Philadelphia and San Diego spectrum marketplace for there to be at least four providers with sufficient spectrum to reach the 60 Mbps of capacity necessary to support 30 simultaneous users of higher definition video in the three city blocks covered by a given antenna sector. In contrast, a single cable-modem user can readily obtain 15 to 50 Mbps of dedicated service.

Rysavy Research projects even an operator with 100 MHz of spectrum and 60 Mbps of aggregate sector capacity will not be able, absent additional spectrum, to meet the data demands of consumers in three to four years if consumers use the applications they desire.[36]

Of course, not all users are necessarily simultaneously engaging in high-bandwidth streaming activities. Users doing e-mail or browsing Web pages with relatively static content consume far less data. So operators can accommodate larger numbers of those kinds of users. The point, however, is that broadband users in general are increasing their data consumption at a steady rate. At the same time, the percentage of subscribers with devices that can consume large amounts of data is growing steadily. For example, the Nielsen Company found that 31% of American mobile consumers owned smartphones

[32] Source: FCC, "Connecting America, The National Broadband Plan," March 2010, at 85.

[33] Source: *FCC*, "Spectrum Dashboard," http://reboot.fcc.gov/reform/systems/spectrum-dashboard (last visited on Mar. 9, 2011). Many of the spectrum holders in Philadelphia and San Diego are Educational Broadband Service (EBS) licensees. Commercial operators are allowed to lease excess capacity on EBS systems but are not eligible to hold EBS licenses.

[34] These spectrum amounts are rough estimates based on the FCC's Spectrum Dashboard. Source: *Id*.

[35] Source: *Id*.

[36] Source: *Rysavy Research*, "Mobile Broadband Capacity Constraints and the Need for Optimization," February 24, 2010, http://www.rysavy.com/Articles/2010_02_Rysavy_Mobile_Broadband_Capacity_Constraints.pdf.

as of December 2010 and more consumers will own smartphones than basic feature phones by the end of 2011.[37] Already today, these nimble tools generate 30 times the data traffic of basic-feature phones.[38] It is the combination of bandwidth-consuming devices and increasing penetration that is placing so much stress on mobile broadband capacity. This trend is now clearly accelerating with the arrival of new device categories, such as tablets, which are being enthusiastically embraced by consumers – 10.3 million tablets sold already with sales expected to exceed laptops by 2015.[39]

To accommodate rapidly rising volumes of data-rich traffic, operators will need to employ multiple approaches. One is to continue deploying more advanced wireless technologies as they become available.[40] Another is to offload data traffic onto alternate networks such as Wi-Fi and femtocells, which have inherently greater capacity due to their much higher frequency reuse. The other tactic, of crucial importance, is to deploy greater capacity in more spectrum, though this is only an option if spectrum is available to them.

Figure 3 shows how the throughput per user can dramatically increase through a combination of offload and more spectrum.

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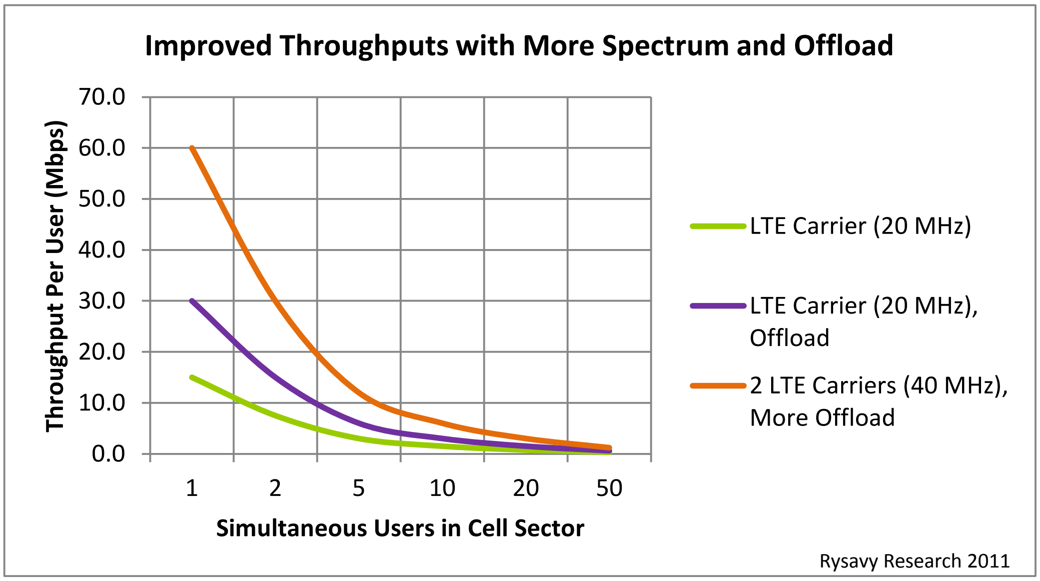
[37] Source: Don Kellogg, "Among Mobile Phone Users, Hispanics, Asians are Most-Likely Smartphone Owners in the U.S.", *NielsenWire*, Feb. 2, 2011, http://blog.nielsen.com/nielsenwire/consumer/among-mobile-phone-users-hispanics-asians-are-most-likely-smartphone-owners-in-the-u-s/#; Roger Entner, "Smartphones to Overtake Feature Phones in U.S. by 2011," *NielsenWire*, Mar. 26, 2010, http://blog.nielsen.com/nielsenwire /consumer/smartphones-to-overtake-feature-phones-in-u-s-by-2011/#.

[38] *Cisco Report*, 2009.

[39] Source: "Tablets to Surpass Laptop Sales In 2015, One Third Of US Consumers Will Own One," MobileMarketingWatch, Jan. 5, 2011, http://www.mobilemarketingwatch.com/tablets-to-surpass-laptop-sales-in-2015-one-third-of-us-consumers-will-own-one-12356/.

[40] For example, the evolution of LTE (through LTE Advanced) employs continually more advanced forms of smart antennas. Rysavy Research projections for required spectrum takes these advances into account.

Figure 3: Greater Capacity Through More Spectrum and Offload[41]




Additional spectrum will play a pivotal role among providers:

- Existing service providers with relatively large amounts of spectrum have huge subscriber bases already generating tremendous broadband demand. This demand will only increase and can only be accommodated with more spectrum.

- Service providers with smaller amounts of spectrum have subscriber bases that are increasingly generating data traffic in addition to high, legacy voice demand. Network capacity based on these smaller spectrum amounts will be rapidly exhausted as these providers increase their subscriber base and as their subscribers consume more data. For example, there are at least three major commercial wireless broadband providers in Philadelphia, and two in San Diego, with less than 50 MHz.[42] All providers will need more spectrum to offer competitive wireless broadband services.

- If there are to be new entrants in the industry, they will also need spectrum.

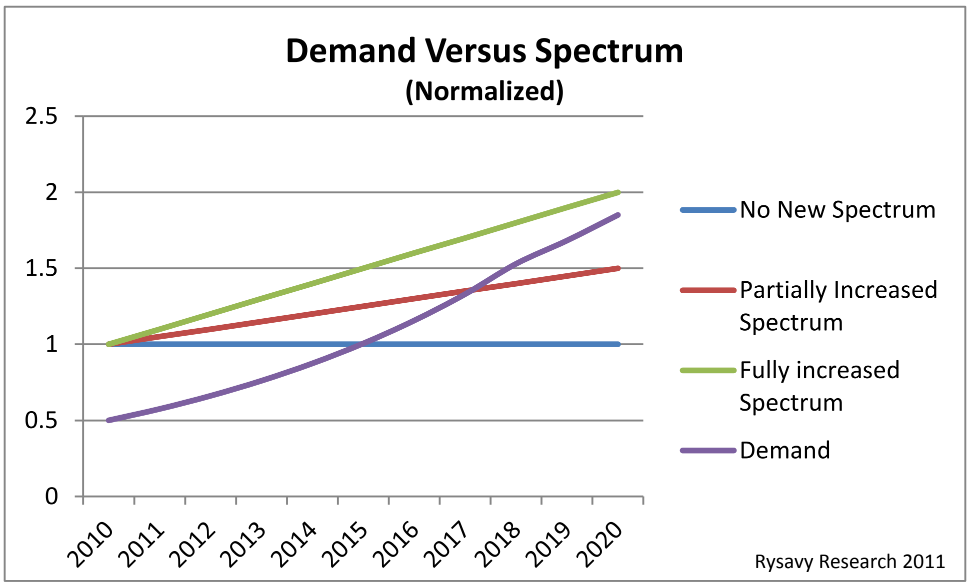
The need for new spectrum is no different when looking at individual operators or the industry as a whole. One way to assess the benefit of new spectrum is to compare the total demand for spectrum across the industry relative to capacity, as shown in Figure 4, which normalizes capacity and spectrum to a value of 1 in 2010. In 2010, the figure shows demand at about half of capacity. The figure depicts

[41] Assumption: as much data offloaded as carried on the LTE network.

[42] Source: FCC, "Spectrum Dashboard," http://reboot.fcc.gov/spectrumdashboard/searchMap.seam.

demand increasing at a fairly rapid rate through 2017 then slowing down thereafter. If no new spectrum becomes available, demand will likely exceed capacity within four years in high-traffic markets. "Partially increased" spectrum is based on a 50% increase of spectrum relative to currently available amounts by 2020. But in this scenario, demand still exceeds capacity within this decade. Fully increased spectrum is based on an approximate 100% increase in spectrum by 2020, as intended by the FCC's National Broadband Plan and the President's Memorandum. It is only through this aggressive allocation of spectrum that demand can possibly be met. Even with this substantial added spectrum, the figure assumes that operators deploy aggressive offload and small-cell architectures, such as femtocells and picocells.

**Figure 4: Demand Versus Different Spectrum Scenarios**




Clearly, additional spectrum contributes directly to increasing capacity. But what does it mean for consumers and U.S. innovation if this spectrum is not made available?

# Adverse Application Effects

The effects of insufficient spectrum are multiple and all negative. One immediate effect is network congestion. Too many users competing for too few network resources cause congestion. This leads to a variety of significant adverse effects in terms of the functionality of the mobile Internet for consumers, including:

- Sluggish behavior (e.g., slow-loading Web pages)
- Stalls (e.g., failures of streaming video like remote health monitoring)
- Complete failure (application or computer system has to be restarted)
- Communications protocols behave erratically (e.g., undelivered packets of data)
- Unpredictable application behavior (e.g. works some times and not others)

Sluggish behavior is easy to understand by taking some typical network configurations and looking at different numbers of users simultaneously loading Web pages. A typical Web page today is over 1 MB in size. Assuming a 1 MB size, Figure 5 shows how page load time increases with higher numbers of simultaneous users. A page load time of greater than 10 seconds represents "sluggish" behavior. For example, this occurs with about 15 users simultaneously accessing Web pages in a 2-HSPA carrier scenario and with about 20 users in an LTE scenario. Doctors in San Diego might be in the office with their wireless tablet trying to access a patient's vital statistics or medical history using the Medical Information Anytime Anywhere application developed by Palomar Pomerado Health officials.[43] In Philadelphia, practitioners might be earning continuing medical education credits through their MedPageToday Mobile application, which contains articles peer-reviewed under the direction of the University of Pennsylvania School of Medicine.[44] Students at the University of California, San Diego may be accessing information about courses or listening to podcasts of prior lectures using the school's iPhone app.[45] A Phillies fan might be trying to order food and drinks at Citizens Bank Park using the At Bat 2010 application.[46] Slow page update times will frustrate these users, and drive them away from these applications and other innovative offerings.

Greater capacity will minimize such sluggish performance. This is not, however, a one-time adjustment. Operators will need to continually augment capacity to address escalating demand.

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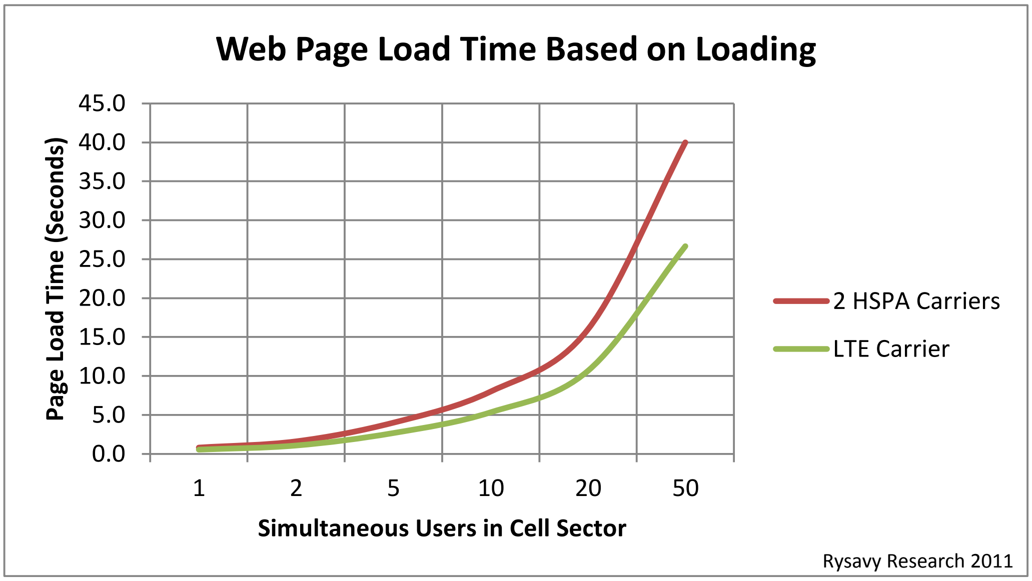
[43] Source: Janet Lavelle, "Wireless Application Would Give Doctors Access to Real-time Records," *San Diego Union-Tribune*, Feb. 20, 2011, http://www.signonsandiego.com/news/2011/feb/20/wireless-device-would-give-doctors-access-real-tim/#.

[44] Source: MedPageToday.com, http://www.medpagetoday.com/iPhone_promo.cfm (last visited Jan. 27, 2011).

[45] Source: Dian Schaffhauser, "UC San Diego Offers Free iPhone App," *Campus Tech.,* June 25, 2009, http://campustechnology.com/articles/2009/06/25/uc-san-diego-offers-free-iphone-app.aspx.

[46] Source: MLB.com, "MLBAM, Philadelphia Phillies & Aramark join to debut Mobile Food Ordering App at Citizens Bank Park" (Sept. 23, 2010), http://mlb.mlb.com/news/press_releases/press_release.jsp?ymd=20100923&content_id=14992180&vkey=pr_mlbcom&fext=.jsp&c_id=mlb.

**Figure 5: Web Page Load Times for Typical Web Pages**




Beyond sluggish performance, there is also the risk that networks that have insufficient capacity (due to insufficient spectrum) have to significantly delay or ultimately drop packets. Packets arrive at a base station or other radio-access network infrastructure node over a high speed connection such as fiber. The base station then transmits the packets over the slower radio connection. If there are too many incoming packets the result will be packets being dropped or significantly delayed. This is an inevitable consequence when there is greater demand than capacity. It is the equivalent of a clogged freeway on-ramp during rush hour. It does not reflect any improper design or management by the operator but a simple overwhelming of the system as it exists today.

In addition to slower performance, outright application failures would become more widespread and commonplace. Most communications protocols implement timeouts on their operations, including Transmission Control Protocol (TCP) itself, the fundamental packet-transport protocol used in the Internet. With large delays or dropped packets, communications protocols will attempt to deliver data reliably. But at some stage of congestion, they can no longer cope properly. At that point, applications will either indicate a failure, or worse, terminate the application and require a full-system restart. This means a user could be in the midst of booking a flight and suddenly they lose their entire session. Or students could be taking exams and lose all of their data.

The worst problem with congestion is that it is unpredictable. A lightly loaded network will function fine, but with more users getting on the network, applications will become unreliable. This "on-again, off-again" mode of operation is frustrating for users, who would grow dissatisfied with the service. When people depend on service, they find it stressful when they cannot rely on it and may well abandon the service if it proves unstable.

## Market Effects

Many service providers, like those in Philadelphia and San Diego, lack the spectrum capacity to meet the rising data demand and will increasingly become capacity constrained as more and more users adopt mobile broadband devices. The resulting effects of congestion will not be isolated to specific industries; rather they will have widely felt adverse effects across finance, telemedicine, education, social networking, research, machine-to-machine connectivity, online gaming and entertainment.[47] Without additional spectrum, an operator's response to congestion can either be to allow it to happen or to implement pricing or other schemes that limit demand.[48] For example, usage caps can limit how much data users consume. In today's market, users can consume a modest amount of streaming content, but they may be reluctant to use a mobile-broadband connection as a substitute for a fixed connection. Users who find the limits to be insufficient to conduct the tasks they want will become frustrated. Higher monthly bills could cause consumers to grow dissatisfied and potentially stop using the service. Moreover, when usage limits are so restrictive that users are uncertain about what they can do or cannot do, they typically opt to do nothing. All of this greatly diminishes the value and appeal of mobile connectivity.

Ultimately, congestion will have a significantly negative effect on the wireless market. Consumers will use the service less.[49] Minorities and lower income groups that increasingly rely only on wireless to access the Internet will be particularly affected by approaches that could limit demand including usage caps, higher pricing and other tools that place a heavy emphasis on data offload, which requires an

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[47] Source: Coleman Bazelon, "The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations," Oct. 23, 2009, at 22 ("Broadband connectivity has measurable impacts on output of the entire economy, well beyond the telecommunications sector.").

[48] Source: Swarup Mandal, Debashis Saha, & Mainak Chatterjee, *Dynamic Price Discovering Models for Differentiated Wireless Services*, 1 J. COMM. 50 (2006) ("[S]ervice providers use pricing as a tool to resolve this constraint on the bandwidth."); Andrew Seybold, "Data Congestion and New Pricing Models," AndrewSeybold.com (June 10, 2010) (stating that while carriers are making technological improvements to increase bandwidth capacity, they still need to "use all of the technology tools that are available along with management tools including pricing."), http://andrewseybold.com/1635-data-congestion-and-new-pricing-models; Aaron Blazar, "AT&T Wireless Data Pricing Changes Analysis," Atlantic-ACM (June 11, 2010) ("Although traffic management efforts have logged some success, the continued growth of usage, and increased penetration of smartphone devices, is driving carriers to reevaluate data plan pricing in efforts to reshape end-user behavior."), http://www.atlantic-acm.com/index.php?option=com_content&view=article&id=534:d ataline-06-10-10&catid=7:datalines&Itemid=5.

[49] Source: FCC, "Connecting America, The National Broadband Plan," March 2010, at 77 ("[S]carcity of mobile broadband could mean higher prices, poor service quality, an inability for the U.S. to compete internationally, depressed demand and, ultimately, a drag on innovation.").

underlying wireline broadband subscription.[50] This will be especially true in urban areas where there are a higher percentage of minorities and people living below the poverty level than the national average. Lower usage also will detract from the investment case across the wireless sector, curbing the growth potential of application developers, mobile device vendors, service providers and operators.[51]

## Conclusion

With exponentially increasing consumer demand, today's mobile broadband market is surging ahead. But the progress is advancing so rapidly that it threatens to quickly exceed the capacity of today's wireless networks. Operators have several methods available to augment capacity, such as increasing the number of cell sites, offloading onto other networks and deploying more efficient technologies. These measures, however, are not sufficient to meet growing market demand. The only viable solution is to allocate more spectrum for these services. More spectrum will allow operators to continue to meet exploding consumer demand, enable new services, and bring even more competition to the market.

Without additional spectrum, technical and market effects will be calamitous. Networks in cities, like Philadelphia and San Diego, will become congested with applications behaving unreliably and erratically. Operators may have no choice but to try to limit demand. As a result, promising advances, like the innovative mobile applications already available to consumers, may not reach the marketplace, investment levels will drop, and the market will not realize its full potential. The U.S. will face the real possibility of losing its global leadership position in this crucially important segment of the economy.

Mobile broadband is not a market unto itself. Rather, it is the intersection of the leading edges of computing, Internet technology and communications technology. Mobile innovation in this country has thrived in an environment of minimal government intervention. But, today, government leadership is urgently needed to make additional spectrum available to power the next wave of connected innovation and growth. Nurturing and expanding this dynamic sector is of vital, strategic importance to this nation.

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[50] Both femtocells and Wi-Fi offload assume a fixed-Internet connection for transporting data to the Internet.

[51] Source: Gerald R. Faulhaber & David J. Farber, *Innovation in the Wireless Ecosystem: A Customer-Centric Framework*, 4 INT'L J. COMM. 73, 82 (2010) ("Customers demand access to the Internet and other data services, so Internet applications are developed, devices become Internet-enabled, and core networks ensure that capacity is available for highspeed data through spectral efficiency innovation. All of this innovation is driven by customer demand; it is *customer-centric innovation.*"); Fairview Capital, "Wireless Innovation: Bridging the Mobility Gap; Industry Overview from a Venture Capital Perspective," (noting that consumer demand for mobile wireless is driving investment in new devices, applications, advertising, mobile payment services, gaming, and infrastructure development), http://www.fairviewcapital.com/images/IndustryReport_Wireless.jpg.