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445 12th Street, SW
Washington, DC 20554

FCC STAFF TECHNICAL PAPER

MOBILE BROADBAND: THE BENEFITS OF ADDITIONAL SPECTRUM

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Federal Communications Commission

Mobile Broadband: The Benefits of Additional Spectrum

Abstract

The National Broadband Plan recommended that the Commission make available 500 megahertz (MHz) of new spectrum for wireless broadband, including 300 MHz for mobile flexible use within five years. In addition, the President directed in a June 28, 2010, Executive Memorandum that 500 MHz of new spectrum for mobile and fixed broadband use. This paper provides additional technical analysis to validate the need for additional mobile broadband spectrum in the near-term, and estimates the value created by making new spectrum available.

Given the inherent uncertainty of any forecast of the future, the goal of this analysis is not to reach definitive numeric findings of spectrum need and economic benefit, but to make a reasonable demonstration that mobile data demand is likely to exceed capacity under current spectrum availability in the near-term, and that meeting this demand by making additional spectrum available is likely to create significant economic value. Our analysis suggests that the broadband spectrum deficit is likely to approach 300 MHz by 2014, that making available additional spectrum for mobile broadband would create value in excess of $100B in the next five years through avoidance of unnecessary costs. This estimate of value creation is narrow, as it does not account for the broader social value created through mobile broadband, which some economists estimate as multiples of the private value. Since making new spectrum available has historically taken between six and thirteen years, and since mobile data growth trends are expected to continue beyond the near-term forecast in this paper, these results support the need for timely action to free spectrum for mobile broadband, consistent with the recommendations of the National Broadband Plan and the President's directive.

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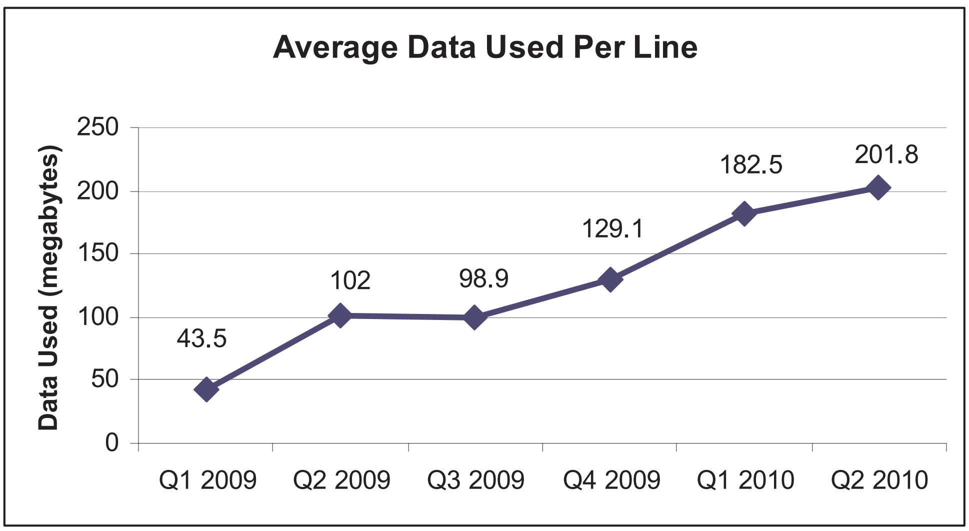
I. Introduction

The National Broadband Plan recommended that the Commission make available 500 megahertz (MHz) of new spectrum for wireless broadband, including 300 MHz for mobile flexible use within five years.[1] In addition, the President directed in a June 28, 2010, Executive Memorandum that 500 MHz of new spectrum for mobile and fixed broadband use.[2] The drive to make available new spectrum for broadband is grounded in strong consumer demand for high-speed wireless Internet access.

Data usage over wireless networks is rapidly increasing as more consumers surf the web, check email, and watch video on mobile devices. In just the latest six months of FCC reporting, subscriptions to mobile data services increased by 40%.[3] And the amount of data used by wireless consumers is increasing substantially – exhibit 1 below shows an increase of over 450% in the amount of data consumed per line between the first quarter of 2009 and the second quarter of 2010.[4]

Exhibit 1: Data Consumption Growth per Line



A range of recent wireless industry trends indicate strong growth of mobile data usage.

- 42% of consumers are estimated to own a smartphone, up from 16% three years ago.[5]

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1 See National Broadband Plan Chapter 5, "Spectrum", at www.broadband.gov

2 President Barack Obama, June 28, 2010, Memorandum for the Heads of Executive Departments and Agencies, "Unleashing the Wireless Broadband Revolution". See http://www.whitehouse.gov/briefing-room/presidential-actions/presidential-memoranda.

3 Internet Access Services: Status as of June 30, 2009, released September 2010 by the FCC's Wireline Competition Bureau.

4 Validas LLC data, September 8, 2010. Found at www.myvalidas.com.

5 Paul Carton and Jean Crumrine, New Survey Shows Android OS Roiling the Smartphone Market, ChangeWave Research, Jan. 4, 2010, available at http://www.changewaveresearch.com/articles/2010/01/smart_phone_20100104.html. Also found at para.159 of the FCC's 14th Mobile Wireless Competition Report. Data period cited is between October 2006 and December 2009.

- PC aircard users consume 1.4 gigabytes (GB) per month -- 56 times the amount of data used by a regular cell phone[6]
- AT&T, the exclusive US carrier of the iPhone, has seen mobile network traffic increase 5,000% over past 3 years.[7]
- Users of Clearwire's fourth generation (4G) WiMAX service consume 7 GB per month -- 280 times the amount of data used by a regular cell phone.[8]

Looking ahead, industry analysts generally share the view that mobile network data traffic will continue a significant upward trend. As smartphones, laptops, and other devices become increasingly integral to consumers' mobile experiences, mobile data demand is expected to grow between 25 and 50 times current levels within 5 years.

The National Broadband Plan ("Plan") recognizes the enormous potential of mobile data growth. To ensure that adequate wireless capacity is available to meet this demand, the Plan calls for an additional 500 megahertz of new spectrum to be made available over the next ten years, including an additional 300 megahertz of spectrum suitable for mobile flexible use within five years.

This paper provides the technical basis for this fundamental recommendation of the Plan. Specifically, by estimating various factors affecting aggregate mobile network capacity and mobile data growth, it is clear that: 1) mobile data demand will outstrip available wireless capacity in the near-term; and that, 2) making available 300 MHz of additional spectrum for mobile broadband is likely to entail economic value of at least $100 billion in the next five years. Also, beyond the five-year forecast period in this paper, mobile data demand is expected to continue its strong growth, supporting the need for action over the longer-term to make available additional spectrum for mobile broadband.

II. Methodological Overview

This paper explores how mobile broadband growth will affect spectrum needs. In addition, recognizing that increasing the amount of spectrum available is one alternative among several to increase mobile network capacity, this paper also estimates the economic effects of making available new spectrum to meet mobile data demand.

First, industry-wide trends and forecasts are used to predict spectrum needs. Industry analysts have predicted total mobile data traffic relative to current levels, and trends such as the

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[6] Validas LLC data, found in the 14th Mobile Wireless Competition Report of the Federal Communications Commission, at para.182, released May 20, 2010. Traditional handsets are estimated to consume approximately 25 MB per month.
[7] Kris Rinne, Sr. Vice Pres. of Architecture & Planning, AT&T, Remarks at the FCC Spectrum Workshop 11–12 (Sept. 17, 2009), available at http://www.broadband. gov/docs/ws_25_spectrum.pdf. Ms. Rinne added that in addition to increased data usage, voice usage continues to rise also. Id.
[8] http://gigaom.com/2010/03/12/clearwires-big-bet-on-our-broadband-addiction/. We note that Clearwire subs typically use the service as a substitute for wired broadband. Traditional handsets are estimated to consume approximately 25 MB per month.

increasing number of cell sites are known and can be extrapolated forward. By adjusting the expected growth in data demand for offsetting growth in network density (which is the result of adding new cell sites) and spectral efficiency, we can forecast future spectrum needs relative to a baseline index of current spectrum in use. Therefore, reasonable approximation of both the baseline and future trends associated with mobile data use and network capacity enable a realistic projection of spectrum need. While the values of these inputs to the model may vary in practice, the incorporation of trends anticipated by relevant experts allows for a cogent forecast.

The output from this approach is therefore an aggregate national projection of likely spectrum needs, which is likely to mask differences across markets, but is nonetheless useful for approximating the economic effects of making new spectrum available for mobile broadband. The projections of mobile data demand used in this analysis are based in part on historic market dynamics, such as "all you can eat" pricing for data. The effect of new pricing strategies on consumer data demand is not yet known, but has the potential to impact data traffic projections if widely adopted in the market.

This paper will demonstrate that even when using conservative assumptions about the market factors that affect spectrum need, it is likely that spectrum will become an increasingly scarce resource in the near term, and that freeing spectrum for mobile broadband use over the next five years will entail significant economic benefits.

The estimate of value created by releasing new spectrum for broadband is narrow, and limited to the avoidance of unnecessary costs but for the new spectrum. This paper does not undertake a comprehensive analysis of the benefits to society that may result from making new spectrum available, which some economists estimate as multiples of the private value.[9] These findings, taken together, clearly support the need for timely action to make new spectrum available for mobile broadband.

III. Traffic Demand and Network Capacity

To determine the need for and benefits of releasing additional spectrum for broadband, the first step is to analyze the drivers of mobile traffic demand and total available network capacity. As illustrated in Exhibit 22 below, the left side of the exhibit, demand – and growth in demand – depends on data consumption by device type and the numbers of each type of device in use.

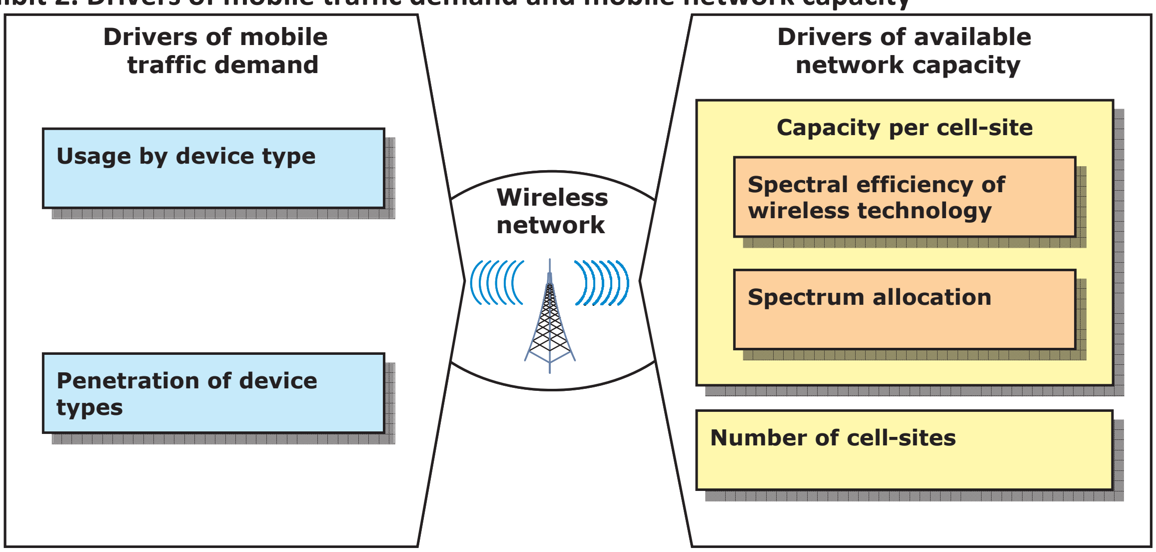
[9] The economic benefits estimated herein represent only the reduction in cost of meeting mobile data demand; no approximation of producer or consumer surplus is offered, and no estimate of exogenous costs is provided. This paper does not estimate the costs to third parties of making available new spectrum, likely auction revenue, or other factors. For a discussion of consumer and producer surplus in the wireless market, see Hazlett and Munoz, "A Welfare Analysis of Spectrum Allocation Policies", RAND Journal of Economics, V.40, No.3, Autumn 2009. Also see Gregory Rosston, "The Long and Winding Road: The FCC Paves the Path with Good Intentions", Telecommunications Policy, V. 27, No.7, August 2003; and, Jerry Hausman "Valuing the Effect of Regulation on New Services in Telecommunications", Brookings Papers on Economic Activity, Microeconomics. Vol. 28 (1997).

An example of demand-side growth is apparent in AT&T's recent experience – as the number of iPhone users has increased, mobile network traffic has increased 5000%.[10]

Network capacity (the amount of data a network can carry), on the other hand, depends on spectral efficiency of wireless technologies (the amount of spectrum needed to transmit a given amount of data), available spectrum, and the number of cell sites used to provide service.[11] In this sense, new spectrum is substitutable, to a point, with capital expenditures to build new cell-sites and develop and implement more efficient wireless technologies.

Therefore, one means of approximating the marginal benefit of allocating additional spectrum for mobile wireless usage is by determining the reduction in incremental costs of substitutes, such as new cell-sites and technologies. In effect, we consider an "indifference curve" between additional spectrum and additional network investment. The indifference curve plots the number of sites and their respective cost against the spectrum required for anticipated mobile data demand in 2014. This method demonstrates different combinations of spectrum and capital needed to meet projected mobile data demand.

Exhibit 2. Drivers of mobile traffic demand and mobile network capacity



This framework of mobile data traffic and capacity enables an understanding of the effects of releasing additional spectrum. Assumptions in this paper could be amended to yield somewhat different numerical benefit estimates; however, any reasonable approximation of relevant variables is likely to confirm the conclusion that releasing additional spectrum will create substantial economic value.

[10] Kris Rinne, Sr. Vice Pres. of Architecture & Planning, AT&T, Remarks at the FCC Spectrum Workshop 11–12 (Sept. 17, 2009), available at http://www.broadband. gov/docs/ws_25_spectrum.pdf. Ms. Rinne added that in addition to increased data usage, voice usage continues to rise also. Id.

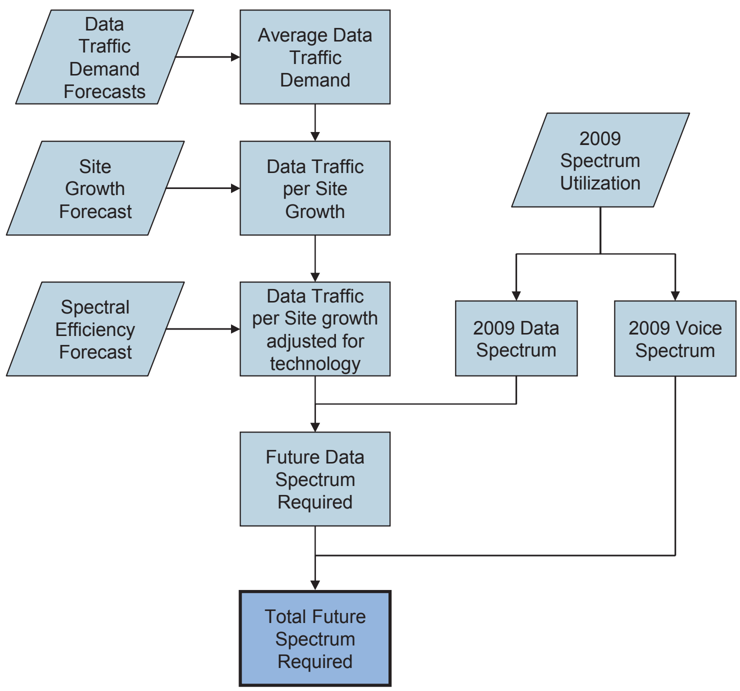
[11] See also FCC OBI Technical Paper, "*The Broadband Availability Gap*", released April 2010.

IV. Model Inputs: Data Demand, Network Density, Spectral Efficiency, and Baseline Spectrum Use

Future spectrum needs can be understood as a function, or multiplier, of current spectrum used for mobile broadband nationwide. The multiplier used in our model is based on an average of reputable industry analyst mobile data demand forecasts, adjusted to account for additional network density via cell site growth and improvements in technology resulting in increased spectral efficiency.

By assuming that spectrum required to support traditional voice will remain at current levels,[12] the total spectrum required in future years is calculated by applying the multiplier only to spectrum used for data during the 2009 baseline year. Current voice spectrum is then added in each year to reach the total. The following flowchart depicts the analytic steps in this model:

Exhibit 3. Top-Down Forecast Flowchart

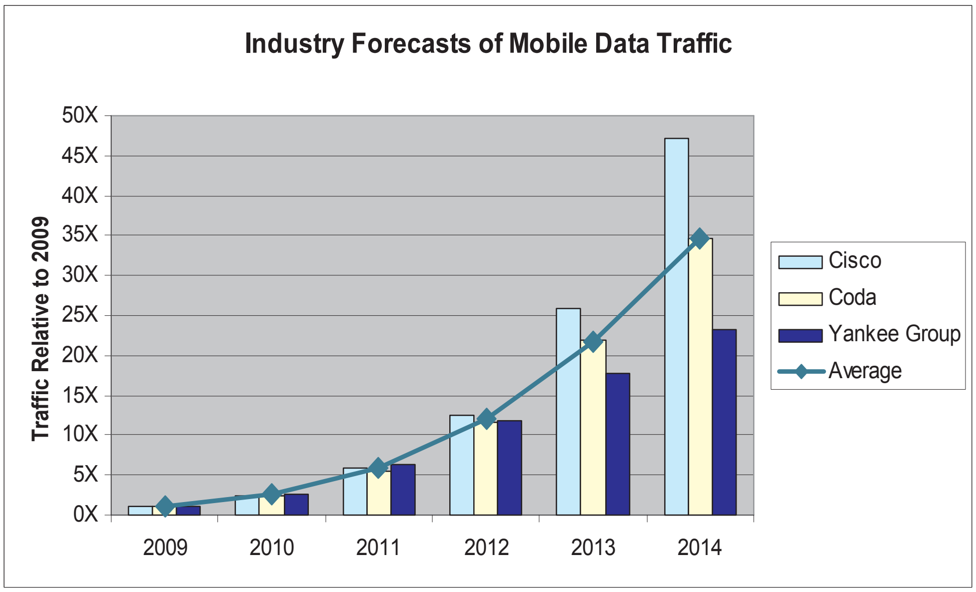


[12] Estimating the rate of voice growth, the rate of voice traffic migration from circuit-switched to VoIP, and the associated spectral efficiency gains, as compared with countervailing considerations such as the proliferation of unlimited talk plans, are beyond the scope of this paper. The actual spectrum required to support traditional voice in the future may be more or less than assumed here; however, given the magnitude of projected mobile data traffic growth, any variance from the constant used in this model will not significantly change the resulting projection of future spectrum needs. In particular, mobile carriers are not expected to fully transition voice services to 4G Internet Protocol within the five-year forecast period.

a. Traffic Demand – Industry-Wide Trends Through 2014

Analysts and industry professionals have forecasted significant future growth in US mobile data usage, though the precise magnitude of projected growth varies between forecasts. A certain degree of uncertainty is expected in any projection of the future. Since the forecasts collectively project a range of future demand, taking an average of three informed industry analyses normalizes the variance across projections. The analyses used in this paper are from the respected industry sources of Cisco Systems, Coda Research, and the Yankee Group. Their quantitative projections of future mobile data demand are shown in the chart below, expressed relative to actual 2009 data traffic.[13]

Exhibit 4. Industry Mobile Data Forecasts



The average of these three projections, as seen in Exhibit 4, reveals strong expected growth in mobile data traffic from 2009 levels – by a factor of five by 2011, more than 20 times by 2013, and reaching 35 times 2009 levels by 2014. In all three forecasts, the trend remains upward in 2014, implying continued growth beyond the forecast period.

Mobile traffic demand is driven by the data usage characteristics of each device type and the numbers of each type of device in use. We briefly review these in the sections below.

Usage by device type

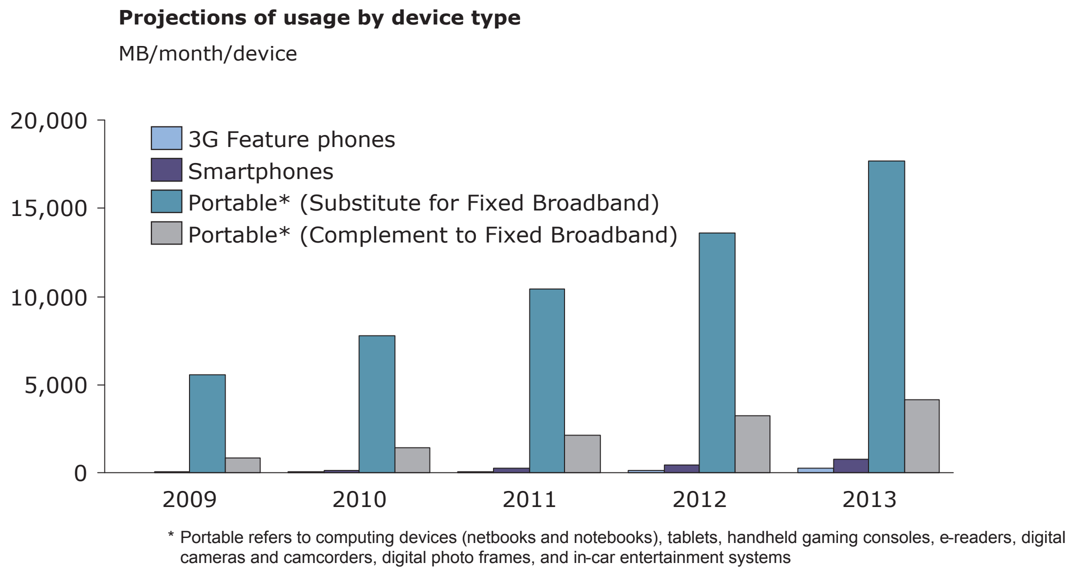
Devices with enhanced functionality tend to consume more data. This is demonstrated in estimates of mobile data use during the second half of 2009 by independent industry analyst Validas. Blackberry, with superior email utility, consumes twice the amount of data monthly as a normal mobile handset. The iPhone, useful for mobile web browsing and applications,

[13] Cisco *Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2009-2014*, February 9, 2010. Coda Research Consultancy, *US Mobile Traffic Forecasts: 2009-2015*, 2009. Yankee Group*, Spectrum-Rich Players Are in the Driver's Seat for Mobile Broadband Economics*, June 2009. See Appendix A of this paper for a methodological summary of each forecast.

consumes five times the data monthly as Blackberry. And aircards, facilitating a full mobile computing experience, consume five times more data monthly than the iPhone.[14] These devices, aggregated across the network, lead to significant total mobile data consumption.

Cisco Systems has produced an estimate of aggregate mobile data consumption by device type between 2009 and 2013, shown in Exhibit 5 below.[15] Consistent with Validas estimates, traffic generated from netbooks and notebooks is highest, especially when the wireless network is used as a substitute for wired broadband connection.

Exhibit 5. Estimate of mobile traffic by device type and forecasts

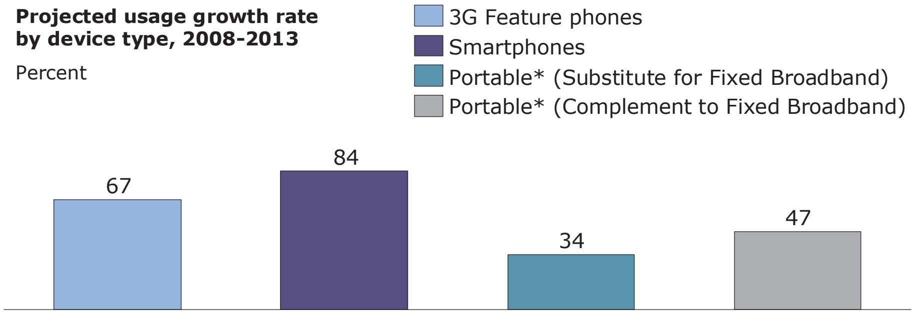


The corresponding growth rate in the amount of data used by device type is shown in Exhibit 6. Note the rapid usage growth projected for all device types, which suggests a doubling of usage almost every two years or less across all devices.

[14] Validas LLC, http://www.myvalidas.com/industryanalytics.aspx. Validas is a company that offers web-based wireless bill analysis and optimization services to consumers and businesses, using data gained from such analysis to provide insight to industry trends.

[15] Ex Parte filing of Cisco Systems in GN docket 09-51, filed March 23, 2010.

Exhibit 6. Projected growth rate of the amount of data used by device type



* Portable refers to computing devices (netbooks and notebooks), tablets, handheld gaming consoles, e-readers, digital cameras and camcorders, digital photo frames, and in-car entertainment systems

When portables such as netbooks and notebooks are used exclusively on the wireless network (i.e., the wireless network is used as a substitute for the wireline network), growth is similar to what is seen on fixed networks.[16] The average monthly usage per subscriber on the Clearwire network, which many consumers use as a substitute for wired broadband, is already 7 GB.[17] Continued growth of this device segment is likely to contribute significantly to the growth of mobile data traffic.

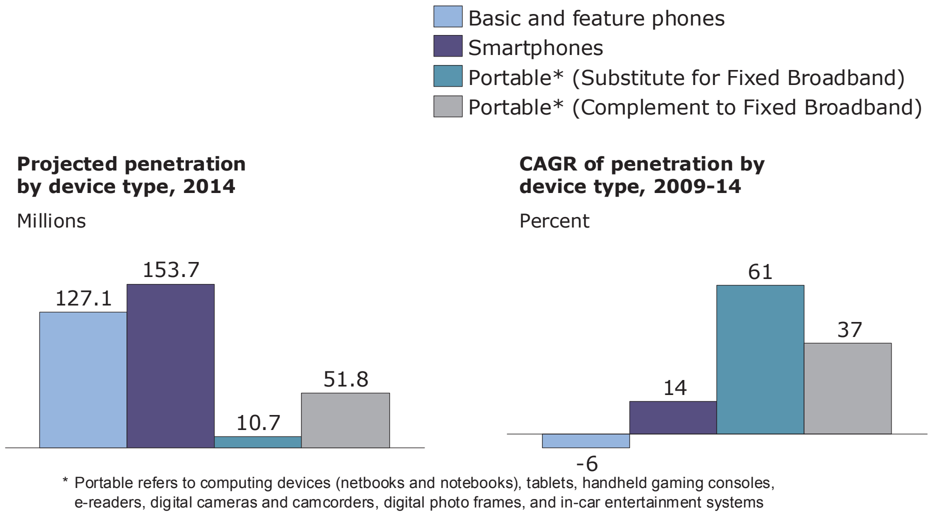
Penetration by device type

The numbers of each type of device in use ("penetration"), as well as the expected growth in penetration, is shown in the exhibit below. Smartphones incorporate the features of traditional, voice-only handsets. So, increasing penetration of smartphones suggests a decreasing penetration of traditional handsets.

Note the rapid growth in penetration expected for portables – the device category also corresponding to highest usage (see Exhibit 7). Further, with relatively modest penetration levels for portables today and ample room for growth, rapid penetration growth could continue beyond 2014.

[16] Cisco *Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2009-2014*, February 9, 2010.
[17] Remarks of Clearwire CEO Bill Morrow at the International CTIA Wireless 2010 show, "Clearwire Extends 4G Leadership In the United States", March 23, 2010.

Exhibit 7. Forecasted numbers of each type of device in use ("penetration") and compound annual growth rate ("CAGR")



Mobile data traffic is a key driver of spectrum need, and as these forecasts show, the consensus among industry experts is that demand for such traffic is likely to increase significantly over the next five years.

The following sections describe other factors such as cell site growth and spectral efficiency that are relevant to estimating spectrum need.

b. Network Density - Cell-Site Growth

Wireless operators continue to invest capital in building new cell-sites. Cell sites can be engineered for different purposes, including increasing capacity, to improve signal quality, and to expand coverage. The latter emphasis expands the operator's footprint; the primary purpose of other so-called "infill" sites is to increase capacity, and in this respect can be conceived as an alternative to new spectrum. The amount of capacity any particular new site adds to a wireless network is difficult to characterize; therefore, we focus on national averages and trends.

According to data published by CTIA, the number of cell sites in the United States has been growing at about a 7% compound annual growth rate (CAGR) over the past five years.[18] This is seen in the following table:

[18] CTIA

Exhibit 8. US Cell-Site Growth since 1997

Date	Total Cell Sites	Year-over-Year Growth	5 Year Running Avg Growth
1997	38,650		
1998	57,674	49%	
1999	74,157	29%	
2000	95,733	29%	
2001	114,059	19%	
2002	131,350	15%	28%
2003	147,719	12%	21%
2004	174,368	18%	19%
2005	178,025	2%	13%
2006	197,576	11%	12%
2007	210,360	6%	10%
2008	220,472	5%	8%
2009	245,912	12%	7%

As Exhibit 8 shows, cell site growth year-over-year has been uneven, but the overall trend in the five year average is that the growth has been slowing.[19] This trend is partly a function of saturation of wireless availability – as an estimated 99.6% of the population now has wireless access,[20] therefore new cell-site growth will emphasize increased capacity.

Projecting new cell site growth is an important input to spectrum demand forecasts. For the purpose of this analysis we will assume flat growth at the 2009 level of 7% over the next five years. This is a more conservative approach than projecting into the future the flattening growth seen in recent years, since new "infill" cell-sites that add capacity are a substitute for new spectrum. Additionally, we assume all future cell site growth will emphasize capacity over coverage, which is also conservative from the standpoint of estimating spectrum needs since new coverage sites do not address capacity constraints.[21]

The assumption of constant cell-site growth at current levels enables estimation of spectrum demand as well as the benefits of releasing additional spectrum. We recognize that since new cell-sites can be a substitute for new spectrum, one might forecast renewed growth acceleration of cell-site construction as mobile data traffic increases, absent constraints relating to location scarcity. Indeed, the rate of cell-site growth increased from 2008 to 2009, and one

[19] The slowdown in site growth is likely a sign of a maturing industry, but may also reflect the increasing difficulty of acquiring sites due to scarcity of locations, zoning, and other constraints. The FCC recently took action to alleviate some of the regulatory barriers to site expansion. See November 18, 2009 Declaratory Ruling in WT Docket 08-165.

[20] FCC estimate based on American Roamer data. Found in the FCC's 14th Mobile Wireless Competition Report, at para.42.

[21] Since this paper is focused on mobile data traffic, strategies to offload traffic to femto-cells and WiFi is not directly considered. In addition, the rollout of such network architecture strategies has been slow to date, and its effects are unclear. For a discussion of this issue, see for example, Rysavy Resarch, "Mobile Broadband Capacity Constraints and the Need for Optimization", updated February 24, 2010.

might expect this to continue if no additional spectrum was to come available. However, by holding cell site growth constant, we are able to compare the marginal cost of meeting mobile data demand by adding new cell sites relative to adding new spectrum. Doing so demonstrates that adding new spectrum will yield substantial economic value.

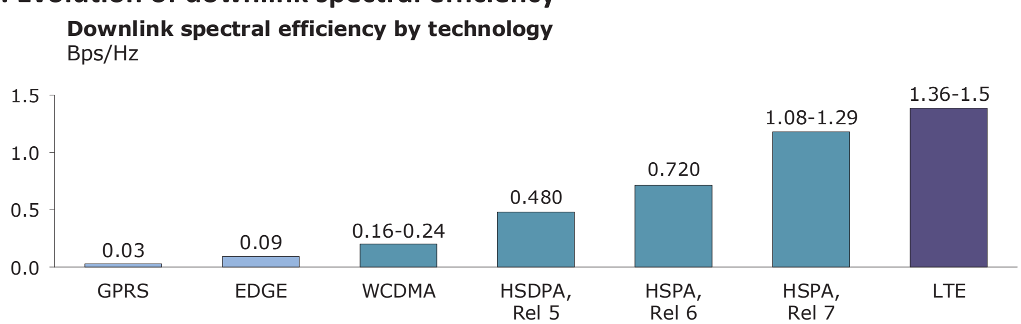
c. Network Capacity - Spectral Efficiency

As wireless technologies have evolved, so has performance. With every evolution, the industry has achieved higher peak data throughputs, improved spectral efficiencies and lower latencies (delays). For example, 4G uses a native, all-IP architecture, thus benefitting from the innovation and cost efficiency of a packet-switched network, relative to legacy circuit-switched technology.

The most important dimension of wireless network performance is spectral efficiency, typically measured in bits per second per Hertz. This metric reflects the amount of data a sector can transmit on a normalized time/bandwidth basis. As such, spectral efficiency drives average downlink data capacity of a cell-site linearly. Exhibit 9 shows the evolution of the average downlink data capacities of a single sector in a 3-sector cell-site for the GSM family of wireless standards.[22]

While 4G technologies have increased spectral efficiency relative to prior generation air interface standards, such gains are likely to become smaller in the future. Indeed, 4G standards achieve improved data throughput by the combined novel use of several technologies, and we do not assume that future gains in throughput will be realized via further innovation on the air interface on a per-device basis, particularly within the five-year time horizon that is the primary focus of this paper.[23] However, as 4G carriers increase as a proportion of total carriers over the next five years, it is likely that overall spectral efficiency will continue to improve.

Exhibit 9. Evolution of downlink spectral efficiency[24]



[22] Qualcomm Ex-Parte filing, "*Spectral Efficiency*", GN Docket No. 09-51
[23] See also OBI Technical Paper, "*The Broadband Availability Gap,*" for additional discussion.
[24] Calculated for a (paired) 2x10MHz spectrum allocation for all technologies. WCDMA performance based on 1x1 and 1x2 antenna configurations; HSDPA Rel 5 and HSPA Rel 6 results based on 1x1 and 1x2 configurations, respectively. HSPA Rel 7 performance assumes 1x2 and 2x2 configurations while LTE result assumes 2x2. Performance of (3G) EV-DO, which is not shown in the chart, is comparable to (3G) HSPA.

Exhibit 9 above shows the spectral efficiency of air interface standards as they have evolved from 2G (GPRS) to 3G (HSDPA) to 4G (LTE). The overall spectral efficiency of all wireless networks can be viewed as a weighted average of the technology mix. Over the next five years the mix is likely to shift from 2G and 3G technologies to primarily 3G and 4G technologies.[25] Our analysis assumes that this will effectively double the average spectral efficiency of wireless networks, from about 0.625 bps/Hz in 2009 to 1.25 bps/Hz in 2014.[26] We should continue to see increased migration from 3G to 4G technologies beyond 2014, resulting in an overall improvement in network spectral efficiency. These spectral efficiency gains serve to reduce network capacity augmentation achieved by adding spectrum bandwidth to meet mobile data demand. Even when accounting for this factor, however, it is clear that additional spectrum will be needed to meet mobile data demand.

d. Baseline Spectrum Use

This forecast of future spectrum needs is based on mobile data demand growth expected from 2009 forward, with offsetting adjustments made for the effect of new cell sites and increasing spectral efficiency. Therefore, we must estimate how much spectrum is used in 2009, including the proportion currently used to support circuit-switched voice relative to the amount used for data.

The FCC's 14th annual Mobile Wireless Competition report described industry trends related to wireless voice service. Of note, the 14th report noted the near saturation of the wireless voice market and the flattening of wireless voice minutes of use, perhaps due to substitution by data services, which are increasing. At the same time, prepaid plans with unlimited voice minutes are increasing and landline phone service is losing ground to wireless service – trends that could offset further decline in wireless voice. Therefore, our present model will assume that the spectrum needed for voice services remains at current levels. The spectrum impacts of any future growth in voice services, driven via prepaid services, population growth, substitution of wireless service for wireline, or other factors, is likely to be offset in the long-term by more efficient handling of voice traffic through 4G Voice over Internet Protocol, though we do not expect a significant transition of aggregate voice traffic to 4G within the five-year forecast period.[27]

In estimating the spectrum baseline we have, again, taken a conservative approach. The National Broadband Plan noted that 547 MHz, in total, is currently licensed under flexible use rules, which allows for mobile broadband and voice services. Of this amount, the 170 MHz that comprise the cellular and PCS bands is the most heavily used. The majority of the remaining

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[25] See, for example, forecasts by WiseHarbor at http://www.wiseharbor.com/forecast.html

[26] While technology will continue to improve, spectral efficiency of current OFDM-based 4G solutions is approaching maximum expected limits. While absolute realized values of spectral efficiency may vary, the projection of increasing efficiency is generally accepted, and its incorporation into the present model appropriately adjusts expected network capacity for this factor.

[27] Based on data from CTIA, the FCC's 14th Wireless Competition report shows that voice minutes declined between 2007 and 2009, while pre-paid subscribers have grown as a percentage of the total subscriber base over the past several years, and also noted a nationwide wireless subscriber rate of nearly 90%. As noted in the report, the decline in voice minutes of use could be related to substantial increases in text messaging, as consumers substitute alternative methods of communication for standard voice.

377 megahertz has been made available within the past six years and is just now coming online.[28] Of course, many of the largest major metropolitan areas are currently using more than 170 MHz of spectrum to support existing voice and data services – for example, T-Mobile has expanded its 3G service in major markets using the AWS band, and Sprint has recently launched its 4G service using the 2.5 GHz band.

Since spectrum is used most intensively in major urban areas, wireless carriers generally prioritize such areas when bringing new spectrum online. However, to model spectrum needs nationwide, we will use 170 MHz as our current baseline, since that amount best reflects frequency use across the country. This is a conservative baseline from the perspective of projecting future spectrum needs, since a smaller starting point effectively increases the availability of currently licensed but not yet built-out frequencies to accommodate future mobile data growth, thereby reducing the additional spectrum that would be needed to accommodate such growth.

Finally, because our forecast focuses on growth in data traffic, the current spectrum use estimates must distinguish between spectrum currently used for voice versus spectrum currently used for data. Information about providers' private allocation of spectrum between voice and data services is not systematically reported and therefore difficult to obtain. Discussions with vendors and carriers suggest that the split for some operators in major markets is approximately 50%/50%. For purposes of the forecast, we have estimated that only 33% of current spectrum is used to support data services and that 67% is currently used to support voice. This approach is conservative in two respects. First, by assuming a larger proportion of voice spectrum use, we protect the model from any unanticipated growth in voice use which is forecasted to be flat. Second, by assuming a smaller proportion of data spectrum use, we decrease the effect of the mobile data demand multiplier that is used to project future spectrum needs. Since the projected growth of mobile data demand is much greater than any possible decrease in voice use or spectral savings related to 4G voice migration in the five-year forecast window, this approach ensures that we do not use uncertainty in baseline spectrum use to inflate our projections.

By making conservative assumptions on the amount of spectrum currently in use, as well as the proportion currently used for voice relative to data, we can gain a reasonable projection of future spectrum needs. To the extent that this forecast is different than actual use in the future, it is more likely to underestimate future spectrum need than to overestimate it. The following section of the paper describes the findings of this methodology.

[28] See National Broadband Plan, at Chapter 5, "Spectrum". Bands recently made available for flexible use that are excluded from the model's current baseline include AWS, 2.5 GHz, and 700 MHz, among others.

V. Model Output: Spectrum Need and Economic Value

a. Spectrum Deficit

Using the methodology described above, we estimate that an additional 275 MHz of spectrum will be required to meet mobile data demand in 2014.

The output of the model is shown in Exhibit 10 below. As detailed in the preceding explanation, the key forecast assumptions and outputs highlighted in Exhibit 6 include:

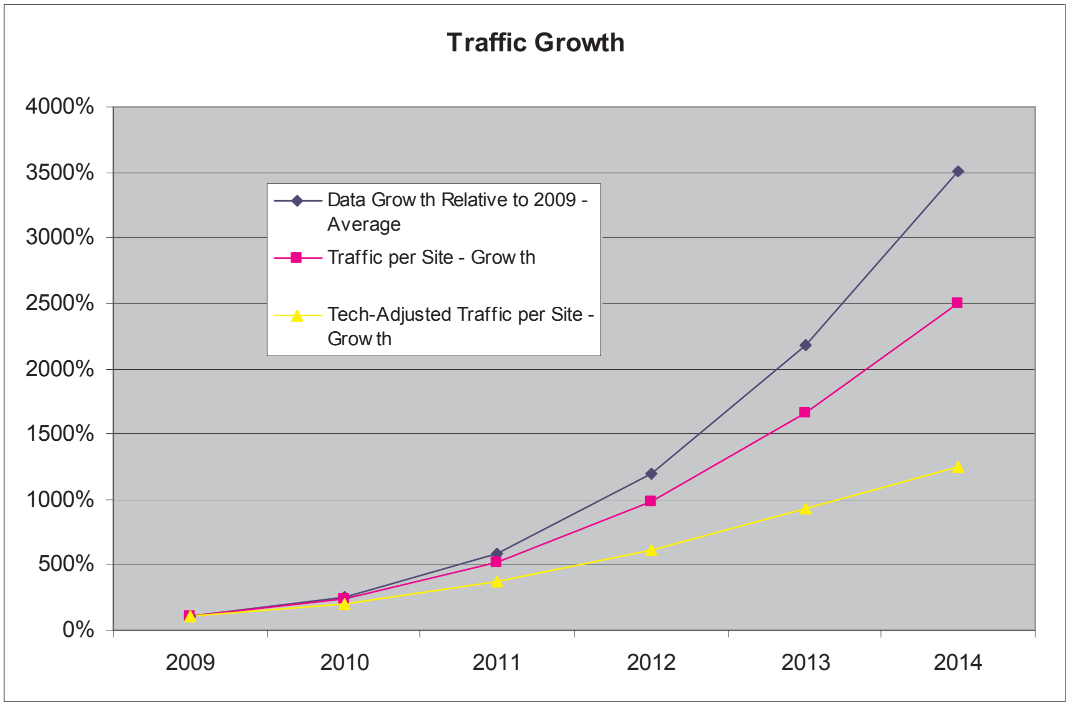
- Total data demand growth relative to 2009 as an average of the three analyst forecasts (line 4), which is a key driver of future spectrum needs.
- Data demand per site adjusted to account for a 7% CAGR in the number of cell sites (line 8), which as a substitute for new spectrum, serves to offset somewhat the amount of spectrum needed in the future.
- Data demand per site adjusted further to account for technology improvements, specifically an increase of spectral efficiency over time (line 11), which is another offset to additional spectrum.
- Total spectrum required to meet the adjusted demand (line 16), taking into account the above three elements.
- The final output is contained in line 18, which shows the spectrum deficit projected for each year through 2014 based on the current mobile broadband spectrum allocation of 547 MHz.

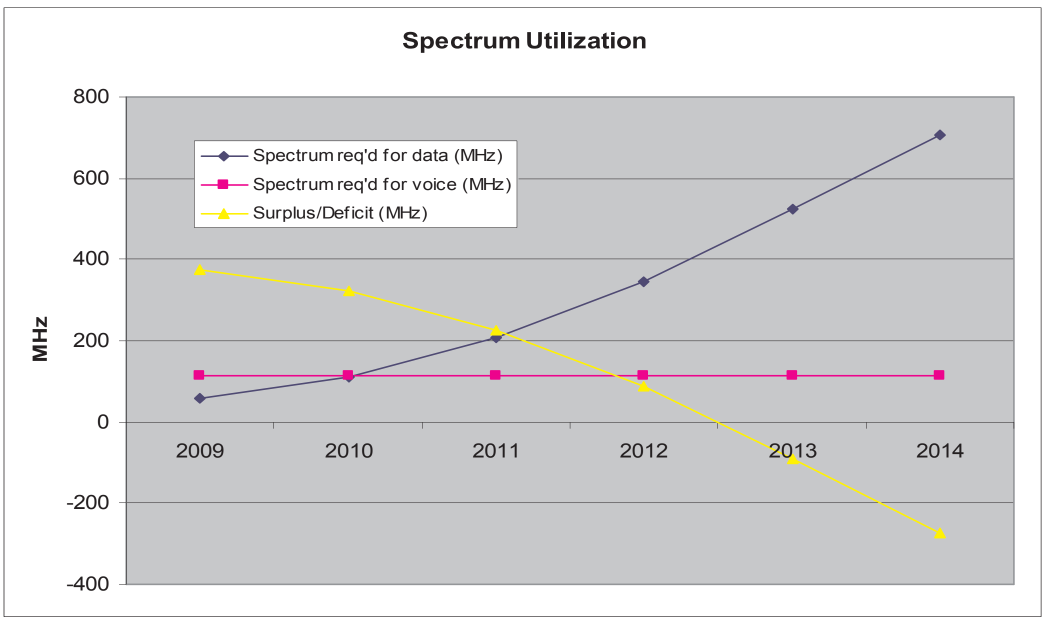
Exhibit 10. Spectrum Need Forecast - Table of Results

	Year:	0	1	2	3	4	5
Line	**Description**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
1	Data Growth Relative to 2009 - Cisco	100%	242%	598%	1253%	2577%	4722%
2	Data Growth Relative to 2009 - Yankee	100%	266%	631%	1189%	1770%	2332%
3	Data Growth Relative to 2009 - Coda	100%	251%	539%	1154%	2200%	3464%
4	**Data Growth Relative to 2009 - Average**	**100%**	**253%**	**589%**	**1199%**	**2182%**	**3506%**
5	Cell Sites	245,912	263,126	281,545	301,253	322,340	344,904
6	Absolute Growth	100%	107%	114%	123%	131%	140%
7	CAGR	**7%**					
8	**Traffic per Site - Growth**	**100%**	**236%**	**515%**	**978%**	**1665%**	**2500%**
9	Avg. Spectral Efficiency (Mbps/MHz)	**0.625**	0.75	0.88	1.00	1.13	**1.25**
10	Absolute Growth	100%	120%	140%	160%	180%	200%
11	**Tech-Adjusted Traffic per Site - Growth**	**100%**	**197%**	**368%**	**612%**	**925%**	**1250%**
12	Spectrum req'd for data (MHz)	57	112	208	346	524	708
13	Percent allocated for data	**33%**	50%	65%	75%	82%	86%
14	Spectrum req'd for voice (MHz)	113	113	113	113	113	113
15	Percent allocated for voice	67%	50%	35%	25%	18%	14%
16	**Spectrum - In Use (MHz)**	**170**	**225**	**322**	**460**	**637**	**822**
17	Spectrum - Currently Allocated (MHz)	547					
18	**Surplus/Deficit (MHz)**	**377**	**322**	**225**	**87**	**-90**	**-275**

Exhibit 11 depicts the traffic growth inputs to the model and spectrum utilization projections. Of particular note is the insight that mobile data demand will exceed available capacity by 2013, and will reach a nearly 300 MHz deficit by 2014. The “Traffic Growth” chart below shows the total assumed data demand from industry forecasts, data demand adjusted for capacity from additional cell sites, and data demand further adjusted for spectral efficiency improvements. The “Spectrum Utilization” chart shows the forecasted data spectrum, the spectrum assumed for voice services, and the spectrum surplus/deficit over time.

Exhibit 11. Traffic Growth and Spectrum Utilization





Even with the conservative set of assumptions used in this model, it is apparent that the nation faces the prospect of a spectrum shortage within the next five years. A later section of this paper undertakes a sensitivity analysis to show how alternative assumptions reinforce this conclusion. While the model does not project beyond this period, a reasonable extrapolation of available data points to the need for ongoing action over the longer-term to make additional spectrum available for mobile broadband.

b. Economic Effects

As noted earlier, increasing network density through the addition of cell-sites is the primary substitute to new spectrum for adding broadband capacity to the network. That is, in the absence of new spectrum, carriers may be expected to increase the growth rate of cell-sites as a means to meet data traffic demands. Therefore, we can use the results of the spectrum analysis above to study the economic benefit of new spectrum relative to this substitute. This is accomplished through an indifference analysis in which the number of sites and their respective cost is plotted against the spectrum required for anticipated mobile data demand in 2014. In effect, we are able generate an indifference curve showing different combinations of spectrum and capital needed to meet projected mobile data demand.

This indifference curve requires an approximation of the cost of a cell site, which is the main capital substitute for spectrum in meeting mobile data demand. For the purposes of our analysis, we have not included the cost of new tower construction because it is likely that the majority of new cell-sites will leverage existing tower infrastructure to add capacity. This is consistent with our prior assumption that all new cell-site growth will be related to "infill" sites, rather than those engineered to expand coverage.[29] Our estimate of the average cost of a cell-site is $550,000, which includes initial site development costs as well as operating expenses.[30] Thus, for example, the cost of a network expansion that involves a hundred additional cell-sites is approximately $55 million plus the cost of the network equipment.

Based on these cost assumptions and the output of the Top-Down forecast, the indifference curve shows that, by 2014, releasing an additional 275 MHz of spectrum saves approximately $120 billion in capital expenses to accommodate mobile data demand.

These estimated savings assume 7% CAGR cell site growth investment, as described earlier. Since this model makes conservative assumptions on the cost of marginal cell-site substitutes, and assumes that there are no exogenous limitations to adding such sites such as local zoning laws, it is possible that the savings related to new spectrum could be even higher than $120 billion.

While modeling precise consumer effects is outside the scope of this paper, it is very likely that these unnecessary costs will affect consumer prices if new spectrum is not made available. And, recognizing that there are likely to be exogenous limitations to the addition of new cell sites, mobile broadband service quality is also likely to suffer if new spectrum is not made available.

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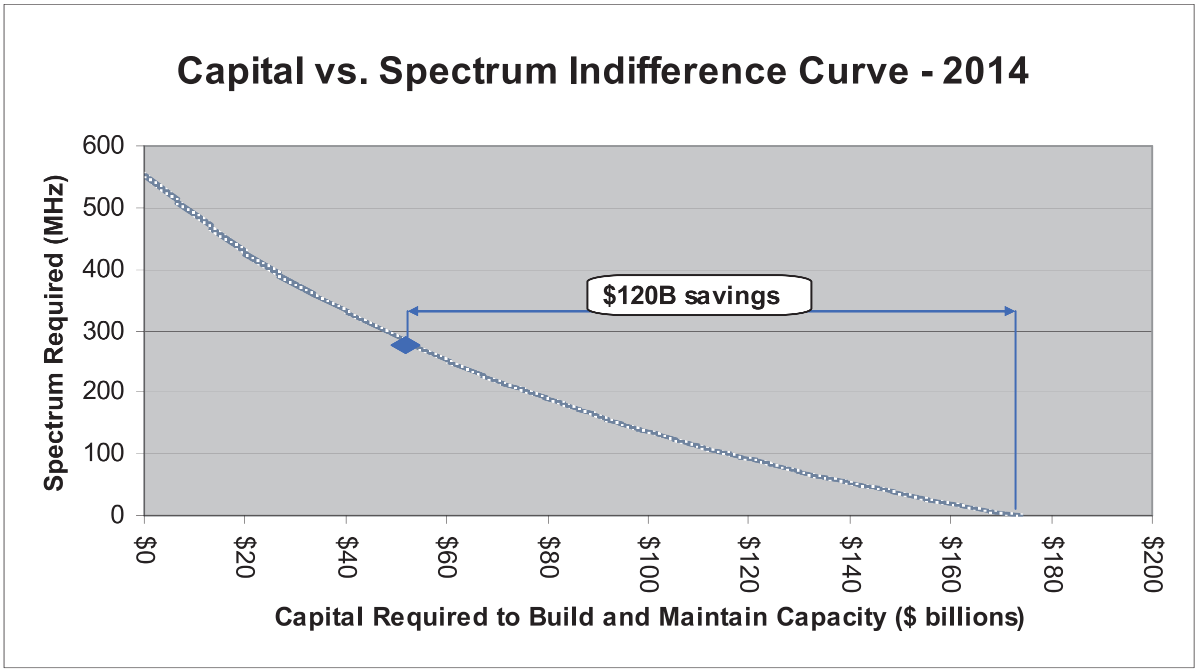
[29] Note that including tower construction costs will only increase the cost of a site , thereby increasing the incremental cost of network capacity expansion. Consequently, cost savings from additional spectrum allocation will only improve if this dimension is added to the analysis.

[30]. See Section VI(c) for an explanation of cell-site costs.

Exhibit 22. Capital vs. Spectrum Indifference Curve for 2014



In Exhibit 12 above, the blue diamond represents the point on the indifference curve corresponding to the 7% CAGR site growth assumptions described above. This represents a capital investment by the mobile broadband industry of $54B in addition to 275 MHz of additional spectrum. The curve implies that if no additional spectrum is released, the cost to build enough capacity sites to handle the demand will be $174B. The difference between these costs represents the value created by additional spectrum in 2014, which is $120B.[31]

This model of national wireless trends clearly supports the National Broadband Plan's recommendation to make available an additional 300 MHz of spectrum in the near-term. Reasonable industry estimates of mobile data demand growth and offsetting capital investment to increase capacity, along with conservative estimates of the amount of spectrum currently used for mobile data, reveal a strong likelihood that demand for data will exceed spectrum capacity over the next five years. The value that will be created by releasing spectrum to meet this demand is significant and likely to exceed $100 billion.

These conclusions are reinforced by testing how possible variances of the model's input assumptions lead to substantively similar conclusions, as discussed in the following section.

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[31] This value is likely to be shared between wireless consumers and carriers; determining the producer and consumer surplus effect is not within the scope of this paper. Also note that the estimate of $120 billion in economic value from the release of new spectrum is likely to be offset somewhat by the costs of acquiring and making use of new spectrum. Spectrum acquisition costs vary as a function of many factors and are not estimated in this paper. Capital costs of upgrading a site to support new spectrum bands are likely to be small relative to total economic value estimates – perhaps several billion dollars – and do not impact the conclusion of substantial economic value resulting from making new spectrum available.

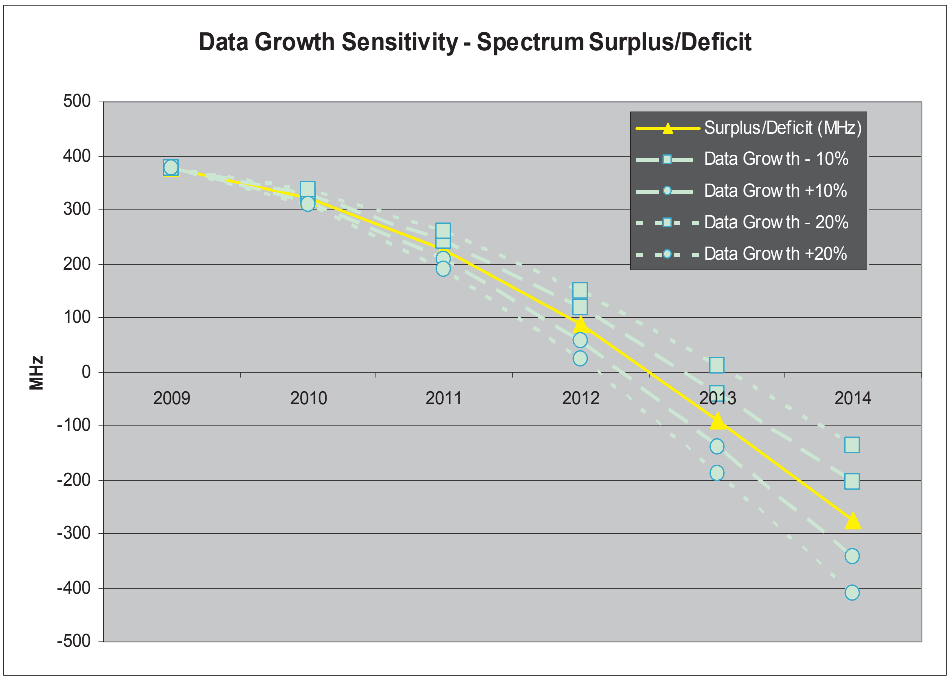
VI. Sensitivity Analyses

Adjusting the input assumptions to the model allows us to understand the sensitivity of the results to potential variance of critical input data. In particular, the output is potentially sensitive to three critical assumptions: the data demand forecast, the baseline amount of spectrum used to serve data traffic, and the cost of meeting data demand through network density.

a. Sensitivity to Data Growth Forecast

Exhibit 13 below shows the effect of adjusting the traffic growth forecast by plus or minus 10% and plus or minus 20%:

Exhibit 13. Data Growth Sensitivity



If the data traffic forecast used is overestimating future demand by 20%, we will still have a spectrum deficit in excess of 100 MHz by 2014. Further, it is reasonable to expect that demand growth will continue into 2015 and beyond, such that the spectrum deficit will continue to grow. For example, if the current deficit curve for 20% over-estimate of data traffic is extrapolated into the future, it appears that the need for 200 MHz will follow shortly after 2014, and 300 MHz will be needed no more than one or two years after.

On the other hand, this sensitivity shows that if the data traffic forecast is underestimating future demand by 20%, the spectrum deficit will reach 300 MHz six to 12 months earlier than currently forecasted, and 400 MHz will be needed by 2014.

b. Sensitivity to Current Amount of Spectrum Used for Data

Recall from the *Baseline Spectrum Use* section that our analysis assumes 170 MHz of spectrum is currently in use in the largest markets that drive the need for spectrum and that 33% of this (or 57 MHz) is used to serve data traffic. This assumption is critical because forecasted spectrum need is a multiplier of the current spectrum used for data, based on the inputs to our model. Since the multiplier in 2014 is about 12.5X, it means that every MHz of input spectrum affects the output by 12.5 MHz. Therefore, the output is very sensitive to this assumption.

Given the fact that 3G technologies such as High Speed Packet Access (HSPA) can serve both voice and data, it is increasingly difficult to separate spectrum used for voice from spectrum used for data. However, given public reports that AT&T has deployed two HSPA carriers[32] in most markets and is adding a third in markets such as New York and San Francisco.[33] Since each HSPA carrier requires 5 MHz uplink and 5 MHz downlink (10 MHz total), it is apparent that at least one operator requires close to 30 MHz to serve the growing appetite for data. Given that AT&T also operates a 2G GSM/EDGE network to serve voice, it is reasonable to assume that most of this 30 MHz is needed for data. If that is the case, then one can conclude that a single operator accounts for about half of the assumed 57 MHz of current spectrum required for data. Given that all large markets are served by at least four operators, and many are served by five, the 57 MHz input assumption appears conservative.

However, if we base the analysis on the majority of large markets as they were deployed in 2009, rather than the high-traffic markets such as New York that are just receiving a third HSPA carrier in early 2010, then we can safely assume that in 2009 AT&T accounted for close to 20 MHz of data spectrum. Although it is not unrealistic to assume that the other three operators can account for the other 37 MHz,[34] we should also consider the possibility that spectrum deployed to serve data was not fully utilized in 2009. If we assume that on average, data spectrum was running at 70% of full capacity, then the resulting assumption is that roughly 40 MHz of spectrum was required to support data services in 2009, instead of the 57 MHz assumed in our primary model.

To reveal the effect of this lower data spectrum baseline, Exhibit 14 shows the indifference curve for 2014, and also projects out to 2016, and 2018 based on the lowest of the three growth extrapolations shown in Exhibit 3. In addition, the 7% CAGR cell site growth is assumed to continue, and spectral efficiency continues to improve, to 1.5 b/s/Hz in 2016 and to 1.75 b/s/Hz in 2018.

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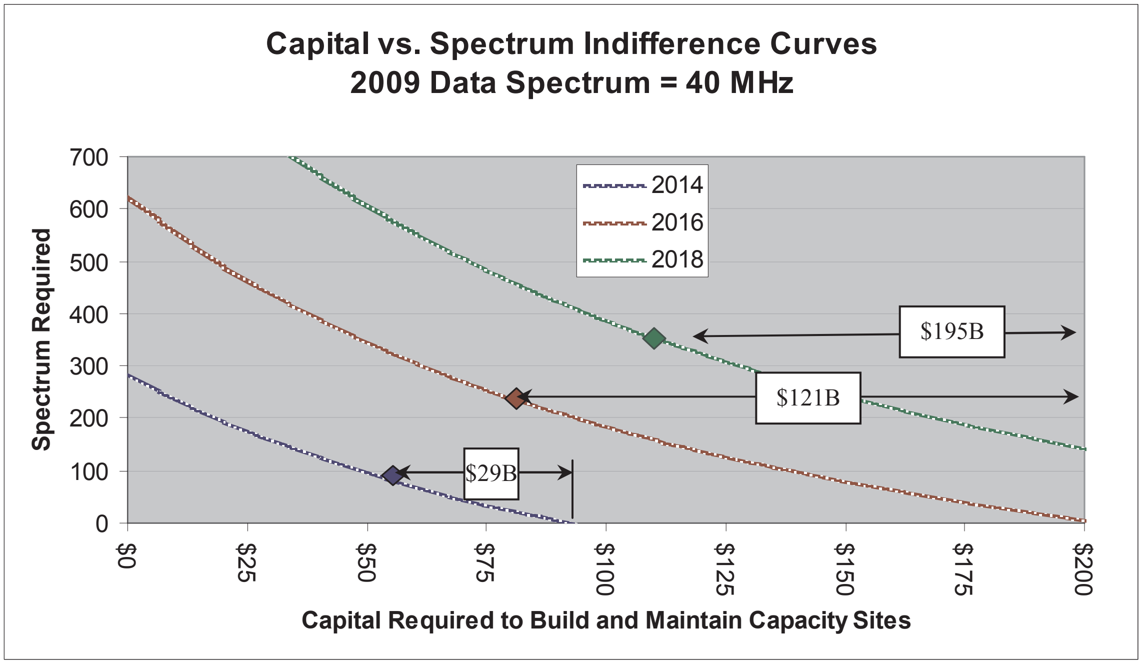
[32] "Carrier" in this use refers to transmission infrastructure, rather than the alternate use of the word to describe a wireless service provider.

[33] Macquarie (USA) Equities Research, AT&T Inc. Network Dinner Takeaways, March 22, 2010 at http://macq.wir.jp/e.ut?e=4rzyJFhQhM54SSBH75Yr4rBt9Kt (last checked March 30, 2010)

[34] For example, it's not unreasonable to assume that two of the three remaining operators require the equivalent of one HSPA carrier and the largest of the three requires the equivalent of nearly two. In addition, a fifth cellular operator is available in many markets, and Clearwire offers 4G data services in several markets, but to be conservative, this spectrum has not been considered.

Exhibit 34. 2014, 2016, & 2018 Indifference Curves for 40 MHz Input Assumption



In this sensitivity analysis, the economic benefit of new spectrum is far smaller in 2014 than in our primary model, at $30 billion instead of $120 billion. However, these benefits continue to increase rapidly beyond the five-year forecast period as mobile data demand continues to grow, even with significant ongoing investment of capital in new sites.

c. Sensitivity to Network Density Cost

The estimated cost to deploy and operate a cell site is an important factor in our analysis, since adding network density in this manner is the primary alternative to new spectrum in meeting mobile broadband demand. Different cell site cost estimates will yield changes to our estimate of economic benefits from making available new spectrum.

The $550,000 unit cell-site cost used in the model is based on initial capital costs of approximately $130,000 (which excludes tower costs as they are generally exogenous to wireless carriers and may not be relevant for all types of cell sites), and includes the net present value (NPV) of approximately $50,000 annual operating expenses over a 20 year period at a 10% discount rate. These calculations are based on discussions with wireless and infrastructure firms and approximate the lifecycle investment cost as the substitute for new spectrum.

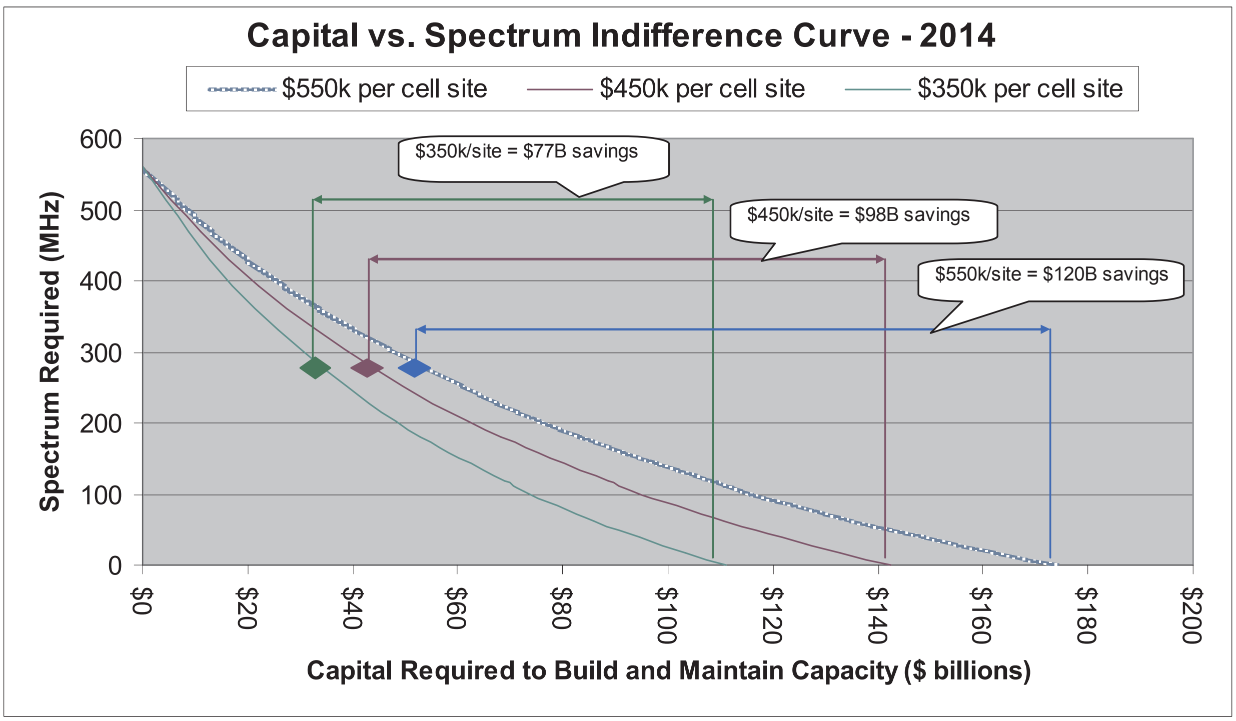
Third-party estimates validate this assumption. Bernstein Research recently estimated the cost to develop a new site at $300,000, while Rysavy Research makes a similar estimate of $250,000 to $350,000. Both estimates are of initial capital expenditures that include tower costs and exclude operating expenses. Taking $300,000 in assumed upfront capital and adding 20-year operating expenses of $30,000 per year (which excludes tower leasing costs) with a 10%

discount rate, to account for the total cost of spectrum substitutes, the NPV of a site is $550,000.

Exhibit 15 below shows the capital – spectrum indifference curve in 2014 for different cell site cost estimates, including $350,000 per site, $450,000 per site, and our primary model estimate of $550,000 per site. While the primary model estimate appears reasonable, this sensitivity analysis enables projections of unexpected circumstances, such as significant amounts of infrastructure sharing among carriers, deflationary supply costs, alternative and less capital-intensive network architectures (e.g., microcells, picocells, and/or distributed antenna architectures), or other economic conditions.

In addition, while the net present value of operating likely operating expenses is included in our primary model estimate of $550,000, the lower $350,000 number can be viewed as a strict comparison of capital expenditures, though it is reasonable to assume that operating expenses would also factor into a full accounting of economic value resulting from new spectrum.

Exhibit 15. Capital Vs. Spectrum Indifference Curve at Different Cell Site Cost Levels



In these circumstances, and holding all else in our primary model constant, the economic benefit of making available an additional 275 MHz of spectrum could be as low as $77 billion at very low cell-site costs. At a cost of $450,000 per site, the benefit of new spectrum is nearly $100 billion. While lower than the $120 billion estimate in our primary model, this sensitivity analysis demonstrates that the economic benefits of new spectrum approach $100 billion by 2014 even with reduced cost of network density alternatives.

Together, these sensitivity analyses show that although model input variables may vary, a spectrum deficit will very likely become significant by mid-decade, and the value of releasing more spectrum appears very likely to surpass $100B in the latter half of the decade at the latest. Given the corresponding possibility of an under-estimation in the model of data growth and current spectrum used for data, the spectrum deficit could be realized sooner, and the value of releasing additional spectrum could be even greater. Since making new spectrum available has historically taken between six and thirteen years[35], and since mobile data growth trends are likely to continue beyond the near-term forecast in this paper, these observations support the need for timely action to free spectrum for mobile broadband.

VII. Conclusion

Mobile broadband services are experiencing significant growth, driven by consumer demand for mobile data. Industry analysts expect this growth to continue, calling into question the capacity of current mobile networks to keep up. Even with substantial investment, it is likely that mobile data demand will exhaust spectrum resources within the next five years. The National Broadband Plan recommended that new spectrum be made available to enable continued growth of mobile broadband.

This paper demonstrates that a spectrum deficit approaching 300 MHz is likely by 2014, and that the benefit of releasing additional spectrum is likely to exceed $100 billion. The model used in this paper is generated from explicit and reasonable market assumptions, which project substantial benefit from releasing additional spectrum for mobile broadband in the near-term.

This paper does not undertake an analysis of net social benefits resulting from making new spectrum available. The economic benefits estimated herein represent only the reduction in cost of meeting mobile data demand. This estimate of value created by releasing new spectrum for broadband is narrow, and limited to the avoidance of unnecessary costs. This paper does not undertake a comprehensive analysis of the benefits to society that may result from making new spectrum available, which some economists estimate as multiples of the private value.[36]

The method used in this analysis to forecast future spectrum need demonstrates the likelihood of enormous economic value being created by releasing 300 MHz of additional spectrum to meet growing demand for mobile data. Given that new spectrum has historically taken between six and thirteen years to make available, and since mobile data growth trends are likely to continue beyond the near-term forecast in this paper, these results support the need for action to implement the National Broadband Plan's recommendation and the President's directive to make new spectrum available for mobile broadband.

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[35] See National Broadband Plan at Ch.5, "Spectrum".

[36] This paper does not estimate the costs to third parties of making available new spectrum, likely auction revenue, or other factors.

Appendix A: Methodology Summary of Mobile Data Demand Forecasts

The three industry analyses used in this paper as a basis for estimating future mobile data traffic arrive at their forecasts through analysis of the likely mix of devices, applications, and services in the mobile market. Each analysis has a distinct methodology, summarized below.

Cisco's VNI forecast methodology begins with the number and growth of connections and devices, applies adoption rates for applications, and then multiplies the application's user base by Cisco's estimated minutes of use and kilobytes per minute for that application. Cisco uses unique data sources, and provides application, segment, geographic, and device granularity, and adjusts for factors such as the likelihood of offloading traffic through means such as Wi-Fi.

Coda's forecast uses data from a variety of sources, including published and unpublished forecasts and survey data. Forecasts of mobile data traffic entail projecting behavior across traffic types and connections and data service take-up, as well as data volumes, data speed and hours per month accessing and generating traffic.

The Yankee Group report uses models of mobile data traffic developed through 20 primary research interviews with technology vendors and service providers to identify trends in the market broadband market. They forecast device migration and data traffic demands across a variety of markets and with several assumed service delivery models.

It should be noted that these analyses forecast technology and market trends based in part on historic experience. There are unknown future variables that could affect projections, such as general economic conditions, and the potential for new pricing strategies such as "tolled" data (i.e., "a la carte", rather than "all you can eat") that can affect mobile data demand.