Substantial Licensed Spectrum Deficit (2015-2019): Updating the FCC's Mobile Data Demand Projections

PREPARED FOR

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I. Introduction

Five years ago the Federal Communications Commission projected a licensed spectrum deficit of almost 300 MHz by 2014.[1] Using the FCC's own formula and approach, we update that forecast and find that by 2019, the U.S. will need more than 350 additional MHz of licensed spectrum to support projected commercial mobile wireless demand. Accordingly, over the next five years the United States (U.S.) must increase its existing supply of licensed broadband spectrum by over 50 percent.[2]

This analysis relies on current projections that demand for wireless broadband capacity, even after accounting for offload to unlicensed services, will increase by six-fold by 2019. Our predictions suggest that just under half of this new demand can be met by increased deployment of cell sites and improved technology, particularly a heavier reliance on 4G and LTE Advanced technologies. In the past six years, wireless operators have invested over $160 billion and, even with additional spectrum, a similar financial commitment will be necessary to enhance and expand networks to help meet significantly higher data volumes.[3]

After accounting for this increased investment by carriers in network technology and infrastructure, we estimate that by 2019 net data demand will increase more than three-fold over 2014 levels. This remaining increase in demand will need to be met by additional licensed spectrum allocations. Importantly, if demand increases faster than expected, if technology deployments lag, or if cell site deployment slows, even more licensed spectrum will be needed. Finally, even if over 350 MHz is repurposed to mobile broadband in the next five years, that spectrum will not address the even greater demand that we expect in 2020 and beyond.

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1 Note, the National Broadband Plan states for 300 MHz of spectrum to be made available by 2015. See FCC, "Connecting America: The National Broadband Plan," Chapter 2, March 2010, at p. 10.

2 There is currently 645.5 MHz of spectrum licensed for broadband. Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the U.S. Economy," Prepared for CTIA, May 11, 2015, at p. 1 ("Bazelon and McHenry, 2015").

3 CTIA, "2014 Data Survey Results: CTIA Survey Documents Dramatic U.S. Wireless Performance," June 17, 2015, at p. 2.

II. Background

A. Spectrum Demand

As demands for wireless services increase, so do the demands for licensed spectrum to provide those services. Over the past four years, increases in U.S. mobile data traffic demand have met the FCC's data growth expectations.[4] According to Cisco, historic mobile data traffic for North America has increased over 11-fold from 49 petabytes per month in 2010 to 563 petabytes per month by 2014.[5] Applying the FCC's growth expectations for 2010 to 2014 to Cisco's 2009 figure implies a projected 562 petabytes per month by 2014 for North America.[6] This is consistent with Cisco's 2014 reported data demand of 563 petabytes per month.[7]

By current estimates and projections, the total volume of mobile data will increase substantially in the next five years.[8] Cisco estimates that by 2019 U.S. mobile data traffic will reach 3.6

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4 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," October 2010. In its 2010 analysis, the FCC used a blended projection based on Cisco, Coda, and Yankee Group projections. At the time, Cisco's expectations were the highest, equivalent to 773 petabytes per month by 2014. See "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2009-2014," Cisco, February 9, 2014, Table 7.

5 For 2010 data, see "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2010-2015," Cisco, February 1, 2011, Table 9. For 2014 data, see "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014-2019," Cisco, February 3, 2015, Table 6.

6 Calculation: 16 petabytes per month in 2009 x 35x growth from data through 2014 ≈ 562 petabytes per month in 2014. The FCC assumes growth in data by 2014 would be 3506%. See FCC, "Mobile Broadband: The Benefits of Additional Spectrum," October 2010, at p. 23. Cisco projected 16.022 petabytes per month of data for North America in 2009. See "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2009-2014," Cisco, February 9, 2014, Table 7.

7 "VNI Mobile Forecast Highlights, 2014-2019: North America," Cisco, available at http://www.cisco.com/assets/sol/sp/vni/forecast_highlights_mobile/index.html#~Country (last accessed June 16, 2015). In 2014 the U.S. accounted for 532 petabytes per month of data, or almost 95 percent of all North America traffic. See "VNI Mobile Forecast Highlights, 2014-2019: United States America," Cisco, available at

http://www.cisco.com/assets/sol/sp/vni/forecast_highlights_mobile/index.html#~Country (last accessed June 16, 2015).

8 For instance, Ericsson also forecasted a rapid growth in data demand. See "Traffic Exploration Data Traffic – Mobile PC/Router/Tablet and Smartphone," available at http://www.ericsson.com/TET/trafficView/loadBasicEditor.ericsson (last accessed June 18, 2015).

exabytes per month, which is a seven-fold increase from 2014.[9] See Figure 1. This increase in traffic will be driven by an increasing number of users (including machine users), more mobile connections per user, and growing demand for faster speeds and more intensive data consuming services, such as mobile video. By 2019, mobile users are expected to increase by 21 million to 290 million, mobile connections will increase by over 600 million to over 1 billion, and mobile video traffic will represent 75 percent of total traffic.[10]

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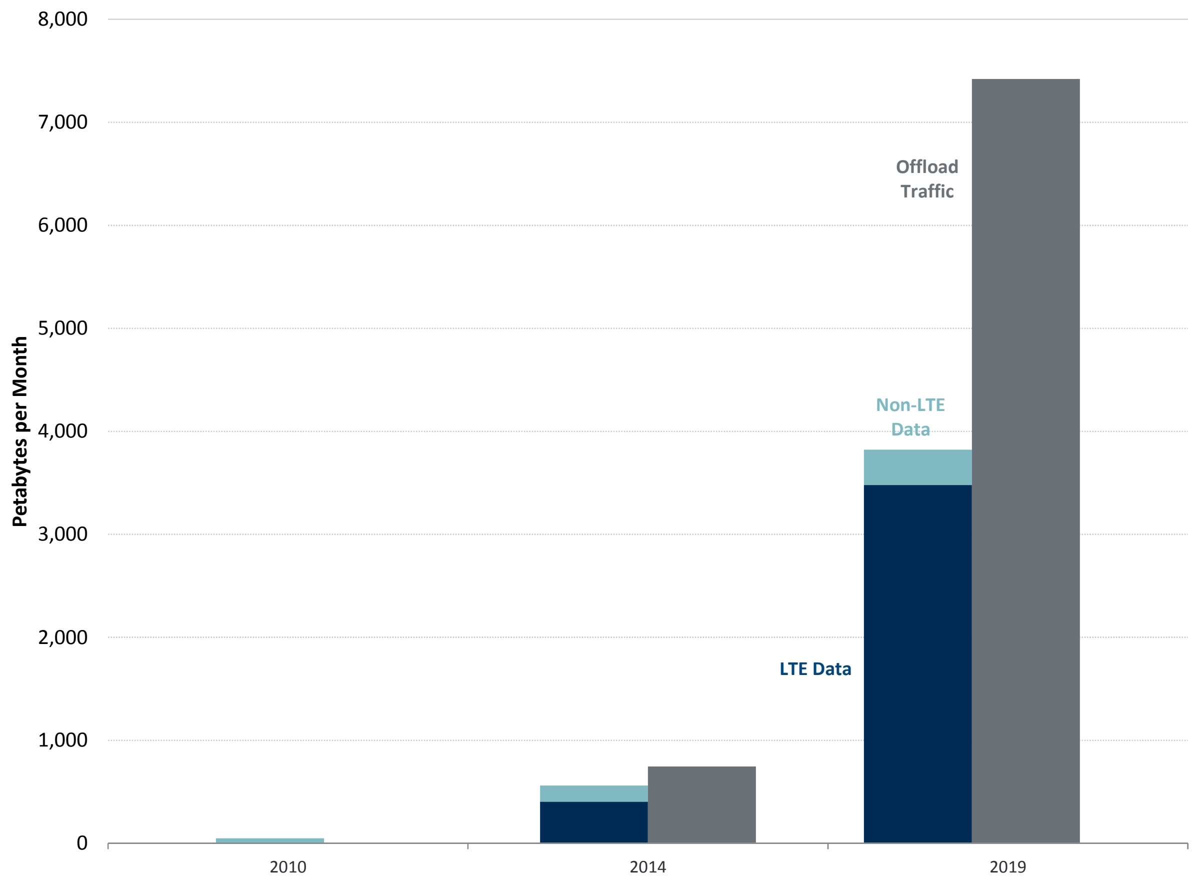
9 Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slide 5. Cisco's definition of mobile data traffic includes devices such as feature phones, smartphones, laptops, tablets, M2M, and other portable devices. Applications include web/data/VoIP, video, audio streaming, and file sharing. See "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014-2019," Cisco, February 3, 2015, Table 6. Our analysis suggests that Cisco's 4-year out data projections from 2009 through 2011 were roughly 15 percent higher than realized data demand. We account for this discrepancy in our projections below. See discussion at Section III.B.1 for more details.

10 Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slide 6.

Figure 1: Wireless Data Demand



Source:

Data based on "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2010-2015," Cisco, February 1, 2011, Table 9 and "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014-2019," Cisco, February 3, 2015, Table 6.

LTE percentage of Offload Traffic based on Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slides 21 and 23.

Although some portion of this increased demand can be met by increasing capital expenditures to deploy new technologies, offload to unlicensed networks, and investment in further network build-out, additional licensed spectrum will also be necessary. Cisco estimates that by 2019, 91 percent of U.S. mobile data traffic will be 4G LTE, up from 72 percent in 2014.[11] These 4G LTE technologies will likely almost double capacity over current 3G technologies.[12]

Moreover, Cisco also estimates that by 2019, twice as much wireless data will be offloaded to unlicensed spectrum as is carried on the macro networks using licensed spectrum.[13] This is up from 2014, when 30 percent more data was offloaded than was carried by macro networks. See Figure 1, above. Accommodating this additional capacity demand will require both additional licensed wireless broadband spectrum and capital expenditures.

B. Adding Capacity: Spectrum versus Infrastructure Complementarity

For wireless broadband networks, there is a necessary balance between the amount of infrastructure and spectrum used. Spectrum-based services require a combination of spectrum and infrastructure to operate. In provisioning a given level of capacity for a network, once the network technology is chosen, up to a point, network operators still face a trade-off between the amount of spectrum and the number of cell sites deployed.[14] At a minimum, a mobile wireless

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11 As indicated by Figure 1, the magnitude of Cisco's overall projections is largely driven by their projections of LTE growth. See Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slide 21.

12 See Table 2 below.

13 Cisco predicts that 66 percent of U.S. mobile data traffic will be offloaded to WiFi networks in 2019. In addition, Cisco estimates that by 2019 63 percent of U.S. mobile device connections will be 4G LTE, up from 41 percent in 2014. See Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slides 15, and 23.

14 The driving innovation behind mobile wireless networks is cellular architecture. By dividing the geographic footprint of radio base stations into small areas, the same frequencies can be reused in non-adjoining cells. When additional capacity is required, this principle can continually be applied by dividing existing cells into smaller and smaller cells, up to a point.

The data capacity of a wireless cell site is roughly dependent on the amount of spectrum and the network technology deployed, regardless of its geographic coverage area. (With very small cells, total capacity may be smaller. See, Richard Clarke, "Expanding Mobile Wireless Capacity: The Challenges Presented by Technology and Economics," *Telecommunications Policy* (2013), p. 6.) Based on its data capacity, a cell site can only cover a fixed number of subscribers in a given area before the quality of service deteriorates. By varying the power of a cell site, its wireless capacity can be spread over a wide geographic footprint if a cell site covers a large area—as would be the case in rural or suburban deployment—or it could cover a small geographic area—as would be the case in a dense urban deployment.

network requires enough cell sites and related infrastructure[15] to cover its entire service area[16] with adequate capacity and sufficient spectrum to carry projected traffic loads. From that point, carriers must increase capacity by either adding additional spectrum or building more infrastructure.

The process of adding more cells, particularly small cells, is time consuming and expensive, and grows increasingly expensive as networks become more capacity constrained. Operators must obtain leases, permits, and attachment rights; install equipment; obtain backhaul; and integrate new cells with the existing network. This requires capital for the construction and equipment and ongoing expense costs for the lease, backhaul, and maintenance. Moreover, obtaining new cell site locations where needed to relieve traffic growth, and ensuring there is sufficient backhaul to support additional cell sites, becomes increasingly difficult. As network density increases, this is particularly the case in urban areas with strict zoning requirements.

The exact mix of spectrum and infrastructure depends on the relative cost of the two inputs. As the value of spectrum increases, wireless service providers are likely to deploy additional infrastructure to more intensively use the available spectrum. Likewise, as it becomes more difficult and increasingly costly to add capacity through infrastructure, it becomes more efficient to use additional spectrum to increase network capacity. Although some portion of the growing demand for wireless services will be met through increase in capital intensity, more spectrum will also be required given the sheer amount of additional data on the networks.[17]

To keep up with increasing demands, carriers will have to continue investing heavily in their network infrastructure, as they have done in the past. From January 1992 to December 2002, wireless carriers spent just over $193 billion dollars on capital expenditures, or roughly $17.5 billion annually. From January 2003 to December 2013, this figure grew to just under $315

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15 The physical infrastructure of a network includes transmission equipment for cell sites, network backhaul facilities and routing equipment.

16 Depending on the propagation characteristics of the spectrum deployed—how the wavelength travels—and the maximum power levels allowed by license, a cell site will have a maximum coverage radius. Within this coverage area, the actual range of a cell is based on design factors such as transmission power levels chosen and various other engineering choices.

17 Increasing capital intensity is also known as deepening the wireless network. Others have recognized that such deepening will not be sufficient to meet future growing demands. See, for example, Richard Clarke, "Expanding Mobile Wireless Capacity: The Challenges Presented by Technology and Economics," *Telecommunications Policy* (2013).

billion dollars, or roughly $28.6 billion annually. This represents a roughly 60 percent increase.[18] This spending continued at this level as carriers spent over $32 billion in capital investment in 2014.[19] On top of those capital expenditures, carrier investments in purchasing licensed spectrum from FCC auctions total $87.3 billion, which does not include currently licensed spectrum that was originally licensed outside of the auction process or sold on the secondary market.[20] Although continued capital investment in mobile wireless is essential, as shown below, it will not be sufficient to meet the growing demand for wireless capacity.

C. U.S. Spectrum Deficit

In 2010, the FCC in its National Broadband Plan targeted approximately 300 MHz of spectrum to be reallocated to mobile broadband within five years, and a total of 500 MHz of spectrum to be reallocated to wireless by 2020.[21] The President subsequently supported the FCC's call for an additional 500 MHz of spectrum.[22] According to the FCC's analysis, making 300 MHz available by 2014 would create over $100 billion in economic value for the country.[23] While growth in data demand has kept up with the FCC's projections,[24] spectrum reallocations have not.

As we previously estimated, of the 300 MHz of spectrum the FCC identified as needed by this year, only 149 MHz has been reallocated.[25] On net, however, there are only an additional 98.5

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18 All numbers are reported in 2013 constant dollars. See CTIA, "That Didn't Take Long…" CTIA Blog, March 4, 2015, available at http://blog.ctia.org/2015/03/04/that-didnt-take-long/ (last accessed June 19, 2015).

19 Figure reported in 2014 dollars. See CTIA, "2014 Data Survey Results: CTIA Survey Documents Dramatic U.S. Wireless Performance," June 17, 2015, at p. 5.

20 For various auction results, see http://wireless.fcc.gov/auctions/default.htm?job=auctions_home. Figure includes auction results for 700 MHz, AWS-1, PCS, H-Block, and AWS-3. This does not include Auction 5: Broadband PCS C Block, which sold for $10.1 billion.

21 FCC, "Connecting America: The National Broadband Plan," Chapter 5, March 2010, at p. 10. We describe the FCC's methodology in more detail at Section III.A.

22 "Presidential Memorandum: Unleashing the Wireless Broadband Revolution," The White House, Office of the Press Secretary, June 28, 2010; and FCC, "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Paper, October 2010, at p. 2.

23 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," October 2010, at p. 2.

24 As described above, wireless mobile data traffic for North America in 2014 was 563 petabytes per month, whereas using the FCC's 2010 growth factor expectations projected that mobile data traffic would be 562 petabytes per month by 2014 for North America.

25 Bazelon and McHenry, 2015, at p. 8. The added spectrum includes 10 MHz of PCS H-Block, 65 MHz of AWS-3, 20 MHz of WCS, 14 MHz of SMR, and 40 MHz of AWS-4. The National Broadband Plan

Continued on next page

MHz available in comparison to 2010.[26] This suggests that the U.S. has met roughly 30 percent of the FCC's five-year spectrum target, creating an even larger future spectrum deficit to be made up by 2020.

Up until now, the industry has worked to meet this data demand with less spectrum than suggested by the FCC in 2010. Over the past five years carriers have met the growing demand for mobile wireless data using a combination of the previously licensed and deployed spectrum and larger capital expenditures. Carriers have been able to deploy spectrum, including the original AWS-1 and 700 MHz allocations that were licensed but generally not yet available for deployment by 2010.[27] Moreover, the increase in data demand was not uniform, as the FCC's model implicitly assumed. As consumers increased their usage, peak busy hour usage continued to grow, but not necessarily in the traditional voice busy hour peaks.[28] With the explosive growth of data and video, and the shift to relatively more usage in non-peak times, it will become increasingly difficult for carriers to meet new capacity demands in the future.

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identified all of this spectrum, except the PCS H-Block and SMR. See FCC, "Connecting America: The National Broadband Plan," Chapter 5, at pp. 76-77.

[26] Bazelon and McHenry, 2015, at pp. 7-9. The FCC estimated 547 MHz of available spectrum in 2010, including 194 MHz of BRS/EBS spectrum and 23 MHz of "other spectrum". The BRS/EBS was reduced to 156.5 MHz when the FCC updated its spectrum screen, reducing the total spectrum inventory by 37.5 MHz (194 MHz – 156.5 MH). We also excluded the 23 MHz of "other spectrum" from our revised inventory, but added 10 MHz of G-Block spectrum that had not been counted for a net reduction of 13 MHz. After this 50.5 MHz (37.5 MHz + 23 MHz – 10 MHz) is netted out, the net added spectrum is 98.5 MHz (149 MHz – 50.5 MHz).

[27] It typically takes at least several years from the time a licensed spectrum band is reallocated and assigned to the point at which the spectrum is ready for a deployment. Among other issues, relocating incumbent users, developing handsets and network equipment, as well as planning and building the network all take substantial time. Moreover, carriers have to carefully plan spectrum deployments in order to have spectrum available for transitions from one technology generation to another.

[28] One analyst has recently compared current wireless networks to mullets, carrying business traffic in the front (during the day) and video and gaming traffic around back (at night). Mitch Wagner, "Networks Are Like Mullets," LightReading, June 15, 2015, available at http://www.lightreading.com/carrier-sdn/sdn-technology/networks-are-like-mullets/d/d-id/716284 (last accessed June 18, 2015). This is a relatively new phenomenon for mobile providers, which has increased the level of traffic during historically off-peak hours. The rise in mobile video demand is also consistent with the rapid, and somewhat unforeseen, shift to tablet devices.

III. Spectrum Forecast

A. FCC's Methodology

This paper updates the FCC's 2010 forecast as reported in the National Broadband Plan. The FCC's analysis started by projecting demand for wireless capacity, using the average forecasts from three different sources: Cisco, Coda Research Consultancy, and Yankee Group.[29] The FCC's analysis projected that demand in 2014 would be 35 times the demand in 2009. As explained above, this projection was very close to reality. According to Cisco, mobile data traffic was 563 petabytes per month by 2014 for North America,[30] as compared to the 562 petabytes per month that would be produced based on the FCC's 2009 growth figure.[31]

The FCC's approach was to calibrate a model of spectrum demand using four inputs:

- Mobile Broadband Data Demand. Using third party estimates, the FCC projected total wireless data demand for mobile networks would grow 35-fold between 2009 and 2014.[32]

- Cell Sites. Based on CTIA projections, the FCC reported 245,912 cell sites in 2009 and projected they would grow by seven percent per year.[33]

- Spectral Efficiency. Recognizing that different generations of wireless technology—2G, 3G, and 4G—had increasing spectral efficiency, the FCC estimated the average efficiency gains based on the mix of subscribers expected to use each technology generation. Their projections included transitioning to 4G, which at that time had not yet been widely deployed. The FCC assumed average spectral efficiency increased from 0.625 Mbps/MHz in 2009 to 1.25 Mbps/MHz in 2014.[34]

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29 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Paper, October 2010, at p. 9.

30 "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014-2019," Cisco, February 3, 2015, Table 6.

31 See footnote 6.

32 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Paper, October 2010, Exhibit 10.

33 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Paper, October 2010, Exhibit 10.

34 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Paper, October 2010, Exhibit 10.

- Spectrum In Use. The FCC estimated the amount of spectrum deployed, or in use, as of 2009 to be 170 MHz, including 120 MHz of PCS and 50 MHz of Cellular.[35] Of that, they assumed that two-thirds of this spectrum (113 MHz) was reserved for voice services, implying that 57 MHz was deployed for data in the base year.[36] The total amount of spectrum estimated to be deployed in each subsequent year was the amount required to make capacity meet demand.

Using these inputs, the FCC projected how cell sites and spectral efficiency would grow from that baseline year to meet demand over time. Based on the remaining growth in data demand that was not accommodated by additional cell sites and spectral efficiency improvements, the FCC estimated the amount of additional licensed spectrum that would be required to meet demand.

For the base year of 2009, the total demand was met by the base year number of cell sites, existing spectrum efficiency and deployed spectrum. The projected increases in cell sites and spectrum efficiency met some of the growing demand; the rest was projected to be met by additional spectrum deployed. Specifically, total projected demand increased by 3,506 percent between 2009 and 2014. After accounting for expected cell site growth and spectral efficiency, the remaining increase in demand that had to be met by additional spectrum was 1,250 percent.[37] In total, the FCC projected 802 MHz would be needed to meet this demand, which was 275 MHz more than the 547 MHz allocated as of 2009.[38] This "nearly 300 MHz" spectrum deficit was incorporated into the National Broadband Plan.

B. UPDATED INPUTS

To provide a new five-year forecast and estimate the spectrum deficit through 2019, we use the same basic methodology that the FCC used for its 2009 estimate, updating assumptions to reflect current usage. These updated assumptions are described below.

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35 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Paper, October 2010, at p. 16; and FCC, "Connecting America: The National Broadband Plan," Chapter 5, March 2010, at pp. 84-85, which shows 170 MHz of PCS and Cellular currently in use.

36 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Paper, October 2010, Exhibit 10. They assumed that the spectrum required for voice remained fixed at 113 MHz, so that only the spectrum required for data would grow.

37 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," October 2010, at Exhibit 10.

38 708 MHz to meet data demand and 113 MHz to meet voice demand.

1. Mobile Broadband Data Demand

Since Coda Research Consultancy and Yankee Group do not have current publicly available estimates, our analysis relies on Cisco's most recent projections of mobile broadband demand. Over the past several years, Cisco has generally published the most robust and detailed estimated projections, and public disclosure of its methods. Consequently, we view their projections as the most appropriate for this context. As discussed in Section II, Cisco estimates that by 2019 U.S. mobile data traffic will reach 3.6 exabytes per month, which is a 7-fold increase from 2014.[39] This demand will come from more users, more mobile connections per user and increased usage. This mobile broadband demand excludes data offloaded to unlicensed networks, which Cisco projects will account for an additional 7 exabytes per month of capacity by 2019.[40] Without this projected growth in unlicensed offloading, the increase from 2014 would be nine-fold.

Nevertheless, Cisco's past U.S. projections have turned out to be somewhat aggressive for certain years; therefore we decided to discount them in order to ensure that our estimates are conservative.[41] We based our discount on the historical accuracy of Cisco's projections four years out.[42] For instance, Cisco's January 2009 projections for 2013 were five percent higher than the

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39 Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slide 5. Cisco's definition of mobile data traffic includes devices such as feature phones, smartphones, laptops, tablets, M2M, and other portable devices. Applications include web/data/VoIP, video, audio streaming, and file sharing. See "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014-2019," Cisco, February 3, 2015, Table 6. Cisco's estimates implicitly assume no change in pricing structure of wireless services. If the spectrum deficit is not addressed, it is likely that wireless service pricing would have to change in order to slow demand for wireless mobile data, and new services and offerings may also be curtailed or delayed.

40 Calculation: (3.6 exabytes per month ÷ (1 – 66 percent)) – 3.6 exabytes per month ≈ 7 exabytes per month. This is based on Cisco's projected 3.6 exabytes per month of U.S. data in 2019, and 66 percent of data offloaded in the U.S. See Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slide 23.

41 An alternative approach would be to take an average of the two publicly available data projections from Cisco and Ericsson. This alternative would reduce Cisco's original data demand growth by 13 percent in 2019. However, Ericsson does not release their projected growth by technology, so we could not properly estimate the growth in spectral efficiency in this case, nor could we replicate the FCC's formula from 2010 using Ericsson data.

42 We chose to compare the fourth year to the first year projections (instead of actual realized demand) to add an additional observation of Cisco's performance. If we were to look at the actual year vs. five-year projections, we would only have two observations, instead of three. If we were to take this approach, the discount would have been 20 percent. Using this 20 percent adjustment would also

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2013 projections for 2013;[43] Cisco's 2010 projections for 2014 were 24 percent higher than their 2014 projections for 2014;[44] and their 2011 projections for 2015 were 16 percent higher than their 2015 projection for 2015.[45] The average of these three data points is 15 percent, which we phase in from 2014 forward.[46]

2. Cell Sites

Consistent with the FCC's methodology, we use the CTIA's Annual Wireless Industry Survey to estimate the total cell sites at the beginning of the period and the annual growth in cell sites. The CTIA Survey reports 298,055 cells sites at the end of 2014.[47] Further, the five year rolling average annual cell site growth has decreased from the seven percent in 2009, as used by the FCC,[48] to about four percent in 2014. We assume, therefore, a four percent annual growth in cell sites persists through 2019.[49] These assumptions suggest that the inventory of U.S. cell sites will

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require adjusting downward the growth of LTE, somewhat off-setting the impact of the adjustment in our projections by also reducing the spectral efficiency gains. Ultimately, we chose to reduce the Cisco forecast by 15 percent, but without an offsetting reduction in efficiency growth.

43 "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update," Cisco, January 29, 2009, Table 1; and "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017," Cisco, February 6, 2013, Table 6.

44 "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2009-2014," Cisco, February 9, 2010, Table 7; and "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018," Cisco, February 5, 2014, Table 6.

45 "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2010-2015," Cisco, February 1, 2011, Table 9; and "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014-2019," Cisco, February 3, 2015, Table 6.

46 We apply the 15 percent discount to ensure that we are being conservative. Our understanding is that prior Cisco estimates relied, in part, on assuming the continued proliferation of mobile netbooks and laptops. This turned out to be superseded by the rise of tablets and smartphone devices. Thus, current Cisco estimates based on expected devices may well prove accurate, which would mean our estimate underestimates the actual amount of spectrum required by 2019.

47 CTIA, "2014 Data Survey Results: CTIA Survey Documents Dramatic U.S. Wireless Performance," June 17, 2015, at p. 5. The survey estimates 298,055 cell sites as of December 2014. The FCC estimated 344,904 cell sites by 2014. As discussed in the text, this number is likely inflated due to recent consolidation of networks. See FCC, "Mobile Broadband: The Benefits of Additional Spectrum," October 2010, Exhibit 10, at p. 18.

48 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," October 2010, at Exhibit 10.

49 A four percent growth rate may prove overly optimistic given the sheer number of cell sites now available, the challenge of identifying new sites, and the proliferation of small versus macro cell sites going forward. Overestimating the growth of cell sites, in turn, overestimates the amount of data

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grow about 22 percent over the next five years, from about 298,055 in 2014 to over 362,269 in 2019.[50] See Table 1.

Given that growth in cell sites has decelerated over time, holding the growth rate constant at its recent historical level may be conservative. Cell site growth has been declining in recent years as certain carriers have consolidated networks or retired legacy 2G-only cell sites. In fact, there was a small reduction in total cell sites in 2014.

Table 1: Forecasted U.S. Cell Sites

Year	Change from 2014	Forecasted Cell Sites
	[a]	[b]
2014	100.00%	298,055
2015	104.00%	309,977
2016	108.16%	322,376
2017	112.49%	335,271
2018	116.99%	348,682
2019	121.67%	362,629

Source & Notes:
[a]: Assume four percent growth each year.
[b]: [a] x 2014[b].

3. Spectral Efficiency

One of the most critical tools for mobile operators to meet the demand growth since 2010 has been the rollout of 4G LTE networks that are dramatically more spectrally efficient than 3G networks. Based on recent technology-specific spectral efficiency estimates published by Peter Rysavy, we assume the current average spectral efficiency by technology. See Table 2. The

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traffic that can be accommodated by cell site expansion, which then underestimates the potential demand for spectrum. Much like the 15 percent discount to Cisco projections, we seek to apply conservative estimates throughout our analysis so as to not inflate the ultimate spectrum deficit figure.

50 CTIA's survey requests carriers report the number of cell sites in commercial service, including macro-cells, micro-cells, and cell-extending devices such as Distributed Antenna Systems and small cells.

Rysavy estimates reflect optimal efficiency, which we reduce by 20 percent to account for actual efficiency.[51]

Table 2: Summary of Spectral Efficiency by Technology

	Technology	Efficiency *bps / Hz*
[1]	LTE+	1.92
[2]	4G LTE	1.12
[3]	3G	0.72
[4]	2G	0.48

Source & Notes:

Rysavy Research, "Beyond LTE: Enabling the Mobile Broadband Explosion," August 2014. We assume that, on average, LTE+ is consistent with spectral efficiency of LTE (4x4), 4G LTE is consistent with LTE (2x2), 3G is consistent with HSDPA (MRxD), and 2G is consistent with EDGE.

To estimate the average annual spectral efficiency across all speeds, we apply these efficiency rates to Cisco's projections of mobile traffic by technology.[52] Within 4G data traffic, we also account for the expected shift to more spectral efficient solutions, such as 4G+.[53] Our analysis suggests that spectral efficiency will increase by over 40 percent by 2019. See Table 3. The shift to 4G+ includes LTE-Advanced capabilities such as Carrier Aggregation, Coordinated Multipoint, Inter-cell Interference Coordination (ICIC), higher order Multiple Input Multiple Output (MIMO) antennas, improved gain from antenna improvements, and improved small cell operation with existing cells. These gains will not likely be deployed widespread, but will be deployed where peak usage demand occurs. While LTE-Advanced has not been widely deployed at this time, including its anticipated adoption significantly lowers the residual demand that must be met by additional licensed spectrum.

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51 Based on discussions with Peter Rysavy in April 2015. This reduction is intended to reflect the real-world complications in network deployments that reduce the efficiency of the network equipment.

52 Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015.

53 For further discussion of 4G+ technologies, see Richard Clarke, "Expanding Mobile Wireless Capacity: The Challenges Presented by Technology and Economics," *Telecommunications Policy* (2013), Table 3.

Table 3: Forecasted U.S. Mobile Spectral Efficiency

		2G	3G	4G LTE	LTE+	Weighted average efficiency *bps / Hz*
		[a]	[b]	[c]	[d]	[e]
[1]	Spectral Efficiency	0.48	0.72	1.12	1.92	
	Share of Traffic					
[2]	2014	0%	28%	72%	0%	1.01
[3]	2015	0%	24%	59%	17%	1.16
[4]	2016	0%	20%	51%	29%	1.27
[5]	2017	0%	17%	50%	34%	1.32
[6]	2018	0%	13%	46%	42%	1.40
[7]	2019	0%	9%	41%	50%	1.48

Sources & Notes:

[1]: Based on spectral efficiency estimates. See Rysavy Research, "Beyond LTE: Enabling the Mobile Broadband Explosion," August 2014, at p. 71. Data reported in bps/Hz.

[2][a]-[7][c]: Based on traffic share estimates. See Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slide 21 and Richard Clarke, "Expanding Mobile Wireless Capacity: The Challenges Presented by Technology and Economics," *Telecommunications Policy* (2013), Table 3.

[2]-[7][d]: [1][a] x [a] + [1][b] x [b] + [1][c] x [c] + [1][d] x [d].

4. Spectrum in Use

We calculate both the total licensed spectrum allocated for mobile broadband uses and the amount of the total that is deployed in our base year of 2014. As discussed above, since 2010 the FCC has released an additional 149 MHz of mobile broadband spectrum, for a net increase of 98.5 MHz, through a combination of spectrum auctions, rebanding, and other rule changes.[54] This represents about one-third of their own goal of reallocating 300 MHz for mobile broadband in five years. As a result, we estimate that there is 645.5 MHz of spectrum available for mobile broadband.[55]

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54 Bazelon and McHenry, 2015, at pp. 7-10. See footnote 26 for further explanation of this calculation. Not all of these additional frequencies are available immediately. For instance, AWS-3 will be available only as incumbent federal users transition out.

55 Bazelon and McHenry, 2015, at p. 8.

We estimate that there was a total of 348 MHz of spectrum in use in 2014.[56] As shown in Table 4, this includes the 170 MHz of PCS and Cellular in use as of 2010,[57] as well as 90 MHz of AWS-1, 64 MHz of 700 MHz, and 14 MHz of SMR. Both AWS-1 and 700 MHz have largely been deployed by carriers.[58] Moreover, we understand that Sprint had deployed SMR for its LTE network by December 2014.[59] Lastly, Sprint uses the 10 MHz G block for LTE.[60]

In contrast to the FCC's assumption that total spectrum needed for voice would be held constant, we recognize that with improving technical efficiency, including such technologies as Voice over LTE (VoLTE), and additional cell sites, this demand will be met with fewer MHz. Consequently, we calculate that instead of the 113 MHz used by the FCC, 63 MHz of spectrum is needed to

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56 As discussed in footnote 27, it typically takes at least several years for bands to be ready for deployment once they allocated and assigned. Since 2014, AT&T has deployed 20 MHz of WCS spectrum. See Phil Goldstein, "AT&T expects to start deploying 2.3 GHz WCS spectrum for LTE this summer," FierceWireless, March 30, 2015, available at http://www.fiercewireless.com/tech/node/69181/print (last accessed May 19, 2015).

57 FCC, "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Paper, October 2010, at p. 16.

58 For example, Verizon runs an LTE network on its 700 MHz C Block, while AT&T planned to use its 700 MHz Lower D and E Blocks for an LTE Broadcast service. See, Phil Goldstein, "Verizon starts deploying LTE in its AWS spectrum," FierceWireless, October 15, 2013, available at http://www.fiercewireless.com/story/verizon-starts-deploying-lte-its-aws-spectrum/2013-10-15 (last accessed May 19, 2015). At this time, it does not appear Dish has deployed its 700 MHz E Block. See, Mike Dano, "Dish proposal hints at plans to deploy LTE across 700 MHz E Block and AWS-4 holdings," FierceWireless, September 11, 2013, available at http://www.fiercewireless.com/story/dish-proposal-hints-plans-deploy-lte-across-700-mhz-e-block-and-aws-4-holdi/2013-09-11 (last accessed May 19, 2015).

In addition, Verizon started deploying its LTE network on its AWS spectrum. See, Phil Goldstein, "Verizon starts deploying LTE in its AWS spectrum," FierceWireless, October 15, 2013, available at http://www.fiercewireless.com/story/verizon-starts-deploying-lte-its-aws-spectrum/2013-10-15 (last accessed May 19, 2015). T-Mobile also has deployed its LTE network on AWS-1 spectrum. See, Phil Goldstein, "T-Mobile to focus on 1900 MHz LTE deployment to expand network footprint," FierceWireless, September 24, 2014, available http://www.fiercewireless.com/story/t-mobile-focus-1900-mhz-lte-deployment-expand-network-footprint/2014-09-24 (last accessed May 19, 2015).

59 Todd R. Weiss, "Sprint's LTE Network is 'Substantially Complete,' CFO Says," eWeek, December 5, 2014, available at http://www.eweek.com/networking/sprints-lte-network-is-substantially-complete-cfo-says.html (last accessed May 19, 2015).

60 Kevin Fitchard, "Sorry, not interested: Sprint bows out of the PCS spectrum auction," Gigaom, November 13, 2013, available at https://gigaom.com/2013/11/13/sorry-not-interested-sprint-bows-out-of-the-pcs-spectrum-auction/ (last accessed May 14, 2015). Although Sprint is planning on using its 2.5 GHz holdings for LTE, it is not generally deployed as of today.

meet voice demand in 2014, falling to 34 MHz by 2019 at which point 97 percent of available spectrum in use will be used to meet data demand.

Table 4: Spectrum in Use as of 2014

	Band Name	Location	Potential Spectrum Supply *MHz*	Currently Deployed *MHz*
	[a]	[b]	[c]	[d]
	700 MHz			
[1]	Paired	700 MHz	58	58
[2]	Unpaired	700 MHz	12	6
[3]	Cellular	800 MHz	50	50
[4]	SMR	800 MHz / 900 MHz	14	14
[5]	AWS-1	1.7 GHz / 2.1 GHz	90	90
[6]	PCS	1.9 GHz	120	120
[7]	G-Block	1.9 GHz	10	10
[8]	H-Block	1.9 GHz /2.0 GHz	10	0
	AWS-3			
[9]	Paired	1.7 GHz / 2.1 GHz	50	0
[10]	Unpaired	1.7 GHz	15	0
[11]	AWS-4	2.0 GHz / 2.2 GHz	40	0
[12]	WCS	2.3 GHz	20	0
[13]	BRS/EBS	2.5 GHz	156.5	0
[14]		**Total:**	**645.5**	**348**

Sources & Notes:

[a]-[c]: Based on Bazelon and McHenry, 2015, at pp. 7-10.

[1]-[7][d]: See discussion above.

[8][d]: The FCC completed its H Block auction on February 27, 2014. See FCC, Public Notice, Auction of H Block Licenses In The 1915-1920 MHz and 1995-2000 MHz Bands Closes (Feb. 28, 2014), https://apps.fcc.gov/edocs_public/attachmatch/DA-14-279A1.pdf.

[9]-[10][d]: The FCC completed its AWS-3 auction on January 29, 2015. See FCC, Public Notice, Auction of Advanced Wireless Services (AWS-3) Licenses Closes (Jan. 30, 2015), https://apps.fcc.gov/edocs_public/attachmatch/DA-15-131A1.pdf.

[11][d]: The FCC adopted flexible use rules for the AWS-4 band on December 11, 2012. See FCC, Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands, Report and Order and Order of Proposed Modification (Dec. 11, 2012), https://apps.fcc.gov/edocs_public/attachmatch/FCC-12-151A1.pdf.

[12][d]: The FCC freed up WCS spectrum for mobile broadband use on October 17, 2012. See FCC, Order on Reconsideration, Amendment of Part 27 of the Commission's Rules to Govern the Operation of Wireless Communications Services in the 2.3 GHz Band (Oct. 17, 2012), https://apps.fcc.gov/edocs_public/attachmatch/FCC-12-130A1.pdf.

[13][d]: While the regulatory history of BRS/EBS spectrum is lengthy, the FCC first took a significant step to enabling mobile broadband in the 2.5 GHz band in 2004. See FCC, Report and Order and FNPRM, Amendment of Parts 1, 21, 73, 74, and 101 of the Commission's Rules to Facilitate the Provision of Fixed and Mobile Broadband Access, Educational and Other Advances Services in the 2150-2162 and 2500-2690 MHz Bands (June 10, 2004), https://apps.fcc.gov/edocs_public/attachmatch/FCC-04-135A1.pdf.

C. ESTIMATED SPECTRUM REQUIREMENTS

Table 5 below presents our results from updating the FCC's 2010 spectrum forecasts, using 2014 as the base year and projecting spectrum demand to 2019. After adjusting for cell site and spectral efficiency growth, traffic per site is projected to grow by an adjusted 343 percent,[61] all of which must be absorbed by spectrum reallocated to broadband in the next five years. Our analysis estimates that demand for spectrum begins to exceed available supply in 2017 and the deficit grows to 366 MHz by 2019. The upcoming incentive auction will meet some of the demand for more licensed spectrum, but even that reallocation will leave significant demand (best case still than two-thirds of the projected deficit) for more licensed spectrum.[62]

Importantly, these projections only cover demand through 2019. Of course, demand for wireless data is expected to continue to increase beyond that date. Beyond 2020, '5G' technology may offer more technology gains, but that will take time to develop and deploy. The FCC's prior effort in 2010 did not make explicit that its spectrum deficit calculation would need to be updated and recalculated to accommodate future growth. Given continued expected explosive growth through 2020 and beyond, and new more efficient technologies, such as 5G, on the horizon, continued re-assessment of the spectrums needs will be required.

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61 This is reflected in row [10] of Table 4 below.

62 This spectrum deficit of 366 MHz must be met by access to spectrum licensed for high power LTE or other deployment, using long term licenses with expectation of renewal. Licensed spectrum in "hybrid" bands with lower power threshold, shorter term licenses would not be sufficient to meet these needs for several reasons. In particular, the technical requirements do not allow for high power 4G LTE deployment. Moreover, the shorter term licenses are likely not sufficient to warrant the investment in such relatively permanent infrastructure. Such hybrid bands may provide opportunities for unlicensed offload, or quasi-offload opportunities, and are part of the FCC's broader spectrum efforts.

Table 5: Spectrum Demand Forecast

	Description	2014 [a]	2015 [b]	2016 [c]	2017 [d]	2018 [e]	2019 [f]
[1]	Data Growth Relative to 2014 - Cisco	100%	151%	229%	337%	481%	680%
[2]	Adjustment to Cisco Projections	0%	3%	6%	9%	12%	15%
[3]	Updated Data Growth Projections	100%	146%	215%	307%	423%	578%
[4]	Cell Sites	298,055	309,977	322,376	335,271	348,682	362,629
[5]	Absolute Growth	100%	104%	108%	112%	117%	122%
[6]	CAGR	4.00%					
[7]	Traffic per site - Growth	100%	141%	199%	273%	362%	475%
[8]	Avg Spectral Efficiency (Mbps/MHz)	1.01	1.11	1.21	1.25	1.32	1.40
[9]	Absolute Growth	100%	110%	120%	124%	131%	138%
[10]	Tech-Adjusted Traffic per Site - Growth	100%	128%	166%	219%	275%	343%
[11]	Spectrum req'd for data (MHz)	285	364	474	625	784	977
[12]	Percent allocated for data	82%	87%	91%	94%	95%	97%
[13]	Spectrum req'd for voice (MHz)	63	54	47	43	38	34
[14]	Percent allocated for voice	18%	13%	9%	6%	5%	3%
[15]	Spectrum - In Use (MHz)	348	418	521	668	822	1,011
[16]	Spectrum - Currently Allocated (MHz)	645.5					
[17]	Surplus/Deficit (MHz)	298	227	125	-23	-177	-366

Sources & Notes:

[1]: Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slide 21.

[2]: Assumption.

[3]: [1] x (1 – [2]).

[4][a]: CTIA, "2014 Data Survey Results: CTIA Survey Documents Dramatic U.S. Wireless Performance," June 17, 2015, at p. 5.

[4][b]-[g]: Previous Year [4] x [5].

[5][a]: Assumption.

[5][b]-[f]: [5][a] x ((1 + [6][a]) ^ (Current Year - 2014)).

[6]: Based on average cell site growth rate from 2009 to 2013. See CTIA, "CTIA Wireless Industry Survey for Year End 2014," 2015, at p. 2.

[7]: [3] ÷ [5].

[6]: Based on spectral efficiency and traffic share estimates. For spectral efficiency, see Rysavy Research, "Beyond LTE: Enabling the Mobile Broadband Explosion," August 2014, at p. 71. For traffic share, see Robert Pepper, "Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019 (Focus on U.S.)," Cisco, February 3, 2015, at slide 21 and Richard Clarke, "Expanding Mobile Wireless Capacity: The Challenges Presented by Technology and Economics," *Telecommunications Policy* (2013), Table 3.

[9]: [8] ÷ [8][a].

[10]: [7] ÷ [9].

[11][a]: [15] - [13].

[11][b]-[f]: [11][a] x [10].

[12]: [11] ÷ [15].

[13]: See discussion at Section III.B.4.

[14]: 1 - [12].

[15][a]: Table 4.

[15][b]-[f]: [11] + [13].

[16]: Table 4.

[15]: [14][a] - [13].

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