May 17, 2016

***Ex Parte* Notice**

Ms. Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

***RE: Connect America Fund,* WC Docket No. 10-90**

Dear Ms. Dortch:

On Monday, May 16, 2016, the undersigned on behalf of NTCA–The Rural Broadband Association ("NTCA") met separately with: (1) Stephanie Weiner, legal advisor to Chairman Tom Wheeler, and Carol Mattey and Alexander Minard of the Wireline Competition Bureau; and (2) Rebekah Goodheart, legal advisor to Commissioner Mignon Clyburn, regarding the framework for competitive bidding under the Connect America Fund ("CAF") Phase 2 program and other universal service fund ("USF")-related matters. The undersigned discussed the same matters with Travis Litman, legal advisor to Commissioner Jessica Rosenworcel, on Tuesday, May 17, 2016.

CAF 2 Competitive Bidding

NTCA first reiterated its support for a competitive bidding framework that looks to measure efficiency and effectiveness based not upon short-term deployment costs, but rather based upon the capabilities that consumers can expect to receive over the life of a CAF-supported network. *See Ex Parte* Letter from Michael R. Romano, Senior Vice President – Policy, NTCA, to Marlene H. Dortch, Secretary, Federal Communications Commission (the "Commission"), WC Docket No. 10-90 (filed July 23, 2015), at 2-3. It will do consumers little, if any, long-term good – and would represent a potentially significant waste of ratepayer resources – to support networks that will be capacity-constrained in short order and/or that are incapable of supporting broadband services at the speeds that will be "table stakes" in five or ten years. As a reminder of the very real engineering issues underlying such decisions, NTCA resubmits here two white papers that it has previously filed in this proceeding regarding the capabilities and limitations of various technology platforms that should be accounted for in designing the competitive bidding framework and related application forms.

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We next discussed the importance of voice services in connection with this next phase of CAF distribution. It is clear as a matter of law that voice telephony remains a supported service. Even if consumer preferences are evolving to include broadband, eligible telecommunications carriers ("ETCs") are also required to offer quality voice services on a standalone basis to consumers at reasonably comparable rates. And, beyond this legal consideration, it would be a stark conflict and jarring juxtaposition indeed for the Commission to downplay or neglect the significance of voice in seeking ways to distribute CAF support to certain parties even as it trumpets the essential nature of voice in other contexts. *See, e.g., Ensuring Continuity of 911 Communications,* PS Docket No. 14-174, Report and Order (rel. Aug. 7, 2015), at ¶ 3 ("[T]he vital importance of the continuity of 911 communications, and the Commission's duty to promote 'safety of life and property through the use of wire and radio communication,' favor action to ensure that all consumers understand the risks associated with non-line-powered 911 service, know how to protect themselves from such risks, and have a meaningful opportunity to do so."); *Proposed Extension of Part 4 of the Commission's Rules Regarding Outage Reporting To Interconnected Voice Over Internet Protocol Service Providers and Broadband Internet Service Providers*, Report and Order, PS Docket No. 11-82 (rel. Feb. 21, 2012), at ¶ 3 ("The availability and resilience of our communications infrastructure, specifically 9-1-1, directly impacts public safety and the ability of our first responders to fulfill their critical mission.")

The availability of quality, affordable, and reliable voice services has thus been a consistent public policy objective of this Commission, and there is neither any sound reason nor any legal basis to vary from that guidepost now to the detriment of rural consumers. It must therefore be made clear in any final order that: (1) providers may not receive CAF support unless they are ETCs that offer voice telephony services at reasonably comparable rates to rural consumers that are capable of providing reliable access to 911 and E-911; (2) providers must not compel consumers to purchase broadband in order to obtain voice service at reasonably comparable rates; and (3) service characteristics such as latency, even if a mere "factor" to be considered in evaluating the overall <u>broadband</u> performance of a provider, must meet a specified level (such as that prescribed by the ITU) that allows reliable two-way <u>voice</u> communication on the supported network.

Finally, NTCA raised the question of how the Commission intends to ensure accountability in the use of CAF funds. In recent orders, the Commission has taken steps to gauge use of CAF resources and advancement of broadband by imposing specific requirements to geocode locations at such time as broadband of certain speed levels are made available there. *See Connect America Fund, et al.*, WC Docket No. 10-90, *et al.*, Report and Order, Order and Order on Reconsideration, and Further Notice of Proposed Rulemaking (rel. March 30, 2016), at ¶¶ 79 and 210; *Connect America Fund et al*., WC Docket No. 10-90 et al., Report and Order, 29 FCC Rcd 15644, 15688-89 (2014), at ¶ 125. The Commission should expect and demand no less of recipients of CAF 2 support obtained through competitive bidding. Specifically, those providers that receive support should be required to show, by reference to geocoded locations, all of those consumers that are in fact able to obtain broadband at the speeds required by the CAF 2 program as a result of the use of CAF 2 resources. To be clear, these reported locations should be tied to real network deployments using CAF 2 resources that enable the actual delivery of services at such speeds assuming *all* consumers in the affected areas were to procure service, and not based upon assumptions as to what *might* be available should *any one* consumer in that area request service.

<u>Other USF Reforms</u>

NTCA further discussed in each meeting its recent filing with respect to the operation of budget controls under the recently released USF reform order, urging prompt consideration of the association's "baseline proposal" and various alternatives put forward. *See Ex Parte* Letter from Michael R. Romano, Senior Vice President – Policy, NTCA, to Marlene H. Dortch, Secretary, Federal Communications Commission (the "Commission"), WC Docket No. 10-90 (filed May 12, 2016).

Thank you for your attention to this correspondence. Pursuant to Section 1.1206 of the Commission's rules, a copy of this letter is being filed via ECFS.

Sincerely,

/s/ *Michael R. Romano*
Michael R. Romano
Senior Vice President – Policy

Enclosures

cc: Stephanie Weiner
Rebekah Goodheart
Travis Litman
Carol Mattey
Alexander Minard

November 7, 2013

***Ex Parte* Notice**

Ms. Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

Re: *Connect America Fund,* WC Docket No. 10-90; *High-Cost Universal Service Support,* WC Docket No. 05-337

Dear Ms. Dortch:

As the Federal Communications Commission (the "Commission") continues to consider the use of a model to distribute Connect America Fund ("CAF") support for price-cap regulated carriers, NTCA–The Rural Broadband Association ("NTCA") submits the enclosed paper by Vantage Point Solutions into the record of the above-referenced proceedings to aid in consideration of potential reliance on "alternative technologies" in "extremely high-cost" areas as identified by such models.

Although NTCA members and other rate-of-return-regulated local exchange carriers ("RLECs") are not subject to the Connect America Fund Phase II mechanisms under Commission rules, as NTCA has indicated in prior filings, certain RLECs may be interested in voluntarily availing themselves of some form of model-based universal service support in the future – although not the precise CAF model being developed now for the larger price cap-regulated companies. *See, e.g.*, Comments of NTCA, *et al.*, WC Docket No. 10-90, *et al*. (filed June 17, 2013), at 11-27; *Ex Parte* Letter from Michael R. Romano, Senior Vice President – Policy, NTCA, to Marlene H. Dortch, Secretary, Commission, WC Docket No. 10-90, *et al.* (filed Sept. 12, 2013), at 9; *see also Wireline Competition Bureau Seeks Comment on Options to Promote Rural Broadband in Rate-of-Return Areas*, Public Notice, DA 13-1112 (rel. May 16, 2013) (seeking comment on "facilitating rate-of-return carriers' voluntary participation in Connect America Phase II"). To the extent that any RLECs may seek to participate voluntarily hereafter in model-based support, however, it is important that the model be calibrated carefully to capture the unique nature of small company operations and challenges. It is also essential as a more general matter that full account is taken of what it may mean for consumers and the very concept of "reasonably comparable" universal service if significant reliance is placed upon "alternative technologies" to provide voice and broadband services in high-cost areas. To help inform this discussion, NTCA submits the attached technical paper discussing the capabilities and limitations of satellite communications services as part of a national universal service strategy.

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Thank you for your attention to this correspondence. If you have any questions, please do not hesitate to contact the undersigned.

Sincerely,

/s/ *Michael R. Romano*
Michael R. Romano
Senior Vice President – Policy

Enclosure

Analysis of Satellite-Based Telecommunications and Broadband Services

November 2013

2211 North Minnesota Street, Mitchell SD 57301 | Phone: 605-995-1777 | Fax: 605-995-1778 | www.vantagepnt.com

Table of Contents

1 Executive Overview

Over the last 50 or more years, satellites have been used to provide a variety of voice, data, navigation, and video services. Satellite communications are better adapted for some services than for others. When used to deliver video services, a single video signal can be broadcast to millions of locations and no additional satellite capacity is required as more customers are added. With interactive two-way traffic, such as voice and broadband data services, complications arise due to limitations innate to satellite communication systems. These complications include the following:

- **High Latency** – The most common satellites used for the delivery of fixed broadband services, geostationary satellites, are located more than 22,000 miles above the equator. Because of this distance from the earth, voice and broadband applications have latency that exceeds industry standards and is more than 20 times the latency of typical landline communications.

- **Capacity Limitations –** Satellite broadband uses a limited amount of spectrum that is shared by all satellite users. As more customers are added or if the existing customers begin to utilize more capacity, exhaustion of satellite capacity can become a significant issue.

- **Environmental Impacts** – Satellite communications become unreliable under certain environmental conditions. The frequencies utilized by satellite systems are susceptible to outages during heavy rain, ice, or snow conditions. In addition, twice a year sun outages occur for many days in a row, and each can last 15 minutes or longer.

The broadband performance of satellite services in terms of latency, jitter, capacity, and speed will always remain inferior to modern fixed wireline technologies. Some satellite limitations may be made less severe with technical advances, but some limitations, such as high latency and weather interference, cannot be solved. While satellites will continue to provide an important role in global communications, satellites do not have the capacity to replace a significant amount of the fixed wireline broadband in use today nor can they provide high-quality, low-latency communications currently available using landline communication systems. While recent advances have increased satellite capacity, the capacity available on an entire satellite is much smaller than that available on a single strand of fiber. These and other satellite communications impairments will be discussed in detail in this report.

2 Introduction to Satellite Technology

This section of the report provides an overview of satellite communications technology, capabilities, and common uses.

2.1 Uses of Satellites

Since the 1950s, satellites have been utilized to provide communications links in areas and situations where wireline technologies were not available and were not feasible to construct. Most communications satellites act as a relay from one point on the earth to one or more other locations or can be intersatellite communications.[1] The information being relayed across a satellite link could be voice, broadband data, and/or video. In some ways, satellite services are similar to those offered by landline providers, but in other significant ways they are different as will be discussed in this paper.

2.2 Satellite Orbits

Satellite orbits can be classified into three main types: geostationary orbits, low earth orbits (LEO) and medium earth orbits (MEO). MEO is mainly utilized for navigation services such as GPS and Galileo, while geostationary and LEO orbits are used for point-to-point and point-to-multipoint satellite communications. Figure 2-1 shows these three orbits.

Geostationary satellite technologies were an early enabler of global real-time communications. Because geostationary satellites orbit the earth at the same speed as the earth's rotation, the satellites appear to be stationary above the earth. To accomplish this, they are placed into orbit more than 22,000 miles above the equator. At this distance, geostationary satellite beams have a direct line of sight to large portions of the earth. Many satellites use Continental US ("CONUS") beams that cover the continental United States. Since the United States is north of the equator, a satellite user must have a clear view of the southern sky. Additionally, since geostationary satellites are positioned over one spot on the equator, the ground station antenna needs to point to only one location to receive the information being transmitted.

[1] Point to point communications is between two fixed locations on earth; broadcast communications is between a fixed location and multiple locations (over a wide coverage area); and intersatellite communications is between two satellites.

Source: GIGAOM

Figure 2-1: Satellite Orbits

Geostationary satellites are effective in delivering certain types of signals to multiple locations simultaneously, such as is the case with broadcast television. Nevertheless, there is very high latency in the communications delivered over geostationary satellites, since the radio signal must travel over 44,000 miles (round trip). To increase the quality of communications signals, MEO and LEO satellites have been used. Because LEO and MEO satellites orbit between a few hundred and a few thousand miles above the earth, they introduce much less latency than geostationary satellites. At these lower altitudes, LEO and MEO satellites orbit the earth rapidly. From a fixed point on the earth, these satellites appear to move across the sky quickly; therefore, many satellites are required to ensure that a subscriber always has a satellite in view. Because of the number of satellites and the intercommunication between satellites and the earth-based devices, LEO systems require sophisticated systems to maintain and hand-off service connections between the orbiting satellites.[2] These systems, when used to provide voice or data to fixed locations on earth, have proven to be complex and expensive to deploy and operate.

2.3 Consumer Service Providers

The following is a summary of the primary providers of satellite voice and data telecommunications in the United States.

Hughes Network Systems

Hughes Network Systems, LLC (Hughes) is a wholly owned subsidiary of EchoStar Corporation. In North America, the Hughes system includes the *SPACEWAY 3* and the recently launched *EchoStar 17* Ka-band geostationary satellites.[3] Hughes claims to serve 660,000 subscribers in North America.[4]

ViaSat

ViaSat delivers geostationary satellite service to residential consumers, businesses, government entities, and the military, and offers fixed and mobile services over ViaSat-1, which ViaSat claims to be the highest bandwidth capacity satellite.[5] In 2009, ViaSat acquired WildBlue[6] and continues to market WildBlue's data and voice service to consumers. Exede, a high-speed Internet offering, is delivered over a combination of the ViaSat-1 satellite and older WildBlue satellites. DIRECTV and DISH also bundle the Exede service as part of their service offerings.

The ViaSat-1 coverage area is prioritized to areas with high population, shown in green on Figure 2-2.[7] The blue areas shown in Figure 2-2 are covered by the older WildBlue satellites.

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[2] For example, the service provider Iridium utilizes a constellation of 66 LEO satellites.
[3] http://www.satellitetoday.com/telecom/2012/07/09/echostar-17-launch-brings-hughes-next-gen-ka-band-into-space/ [URL verified on September 22, 2013]
[4] http://www.hughes.com/company/about-us [URL verified on September 22, 2013]
[5] http://www.viasat.com/company [URL verified on September 22, 2013]
[6] http://www.viasat.com/news/viasat-acquire-wildblue-communications [URL verified on September 22, 2013]
[7] http://arstechnica.com/business/2012/01/how-viasats-exede-makes-satellite-broadband-not-suck/ [URL verified on September 22, 2013]

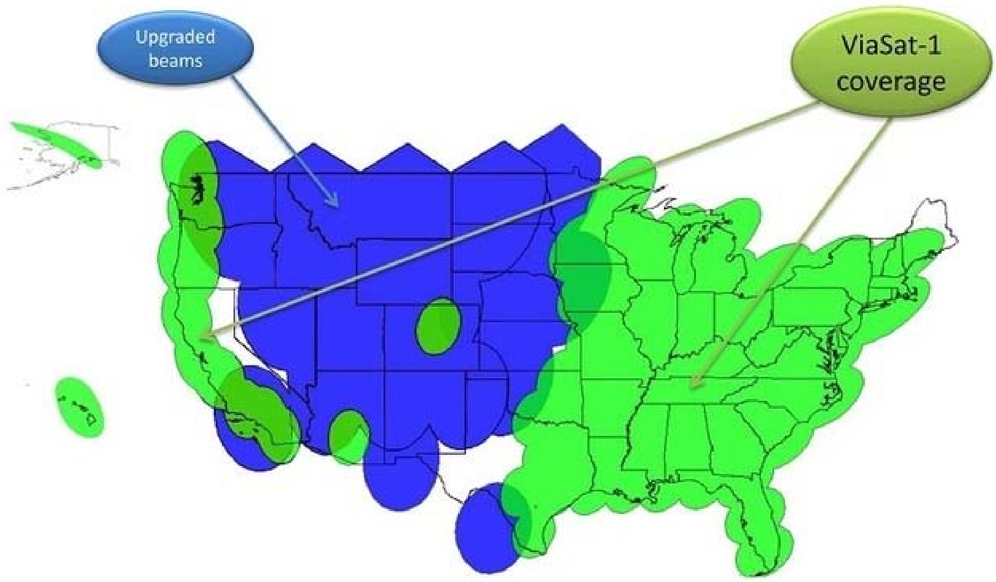

Figure 2-2: ViaSat Exede Coverage

The lower data capacity on WildBlue satellites caused ViaSat to suspend new installations in many areas over the past several years.[8] For example, Figure 2-3 shows an Exede website message for service availability for a South Dakota location when attempted on September 22, 2013.

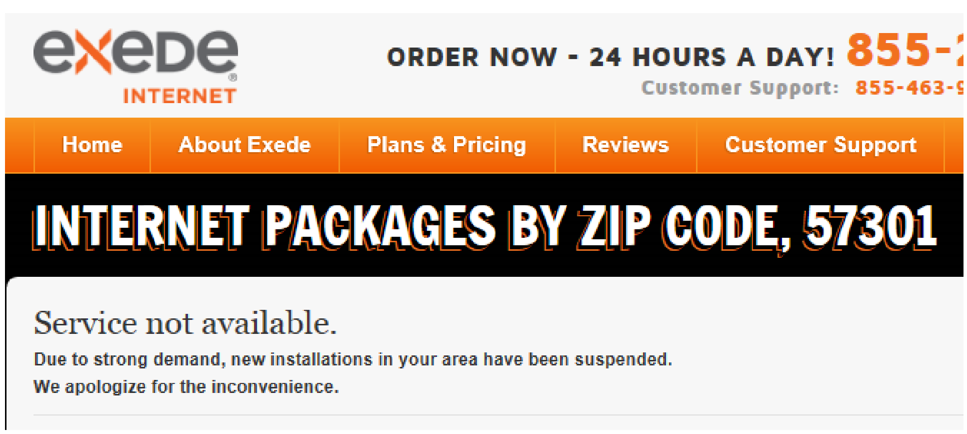

Figure 2-3: Exede New Installations Suspension Notice [https://order.exede.com]

[8] http://www.dslreports.com/shownews/ViaSat-WildBlue-Launching-50-12-Mbps-Service-Next-Week-117744 [URL verified on September 22, 2013]

Iridium Satellite

Iridium is a LEO satellite communications provider originally formed as a Motorola spinoff. The Iridium network consists of a constellation of 66 satellites. In 1999, Iridium World Communications filed for Chapter 11 bankruptcy as a result of high infrastructure costs and low subscriber penetration.[9] Iridium's network was purchased in 2000 for $25 million (the Iridium network originally cost approximately $5 billion), and the company was restructured as Iridium Satellite.[10] Iridium has a major program underway for its next-generation network, Iridium NEXT.[11]

Globalstar

Globalstar is another LEO provider of mobile satellite voice and data services. The company filed for bankruptcy in 2002 and emerged from bankruptcy in 2004.[12] Globalstar appears to be looking to repurpose the spectrum currently used for satellite into terrestrial wireless spectrum because it has asked the FCC to convert 80 percent of its spectrum to "Wi-Fi type" service[13] and has been testing with Amazon.[14]

2.4 Services

Both geostationary and LEO service providers offer voice service. Due to the shorter distance that must be traveled by the radio waves, LEO networks have much lower latency than geostationary networks. LEO providers have focused on providing mobile voice services for industries that operate in remote locations such as maritime, aviation, mining, oil and some remote emergency services.[15] The Iridium and Globalstar packages range from $25 to $265 per month depending on the number of minutes included in the package. The geostationary providers market their voice packages to residential and business consumers. These packages normally range from $20 to $30 per month with unlimited minutes.

Competitive satellite broadband services in the United States are currently only provided by geostationary providers. LEO satellite providers focus on mobile voice services and only provide low

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[9] http://news.cnet.com/Iridium-knocked-back-to-earth/2100-1033_3-224895.html and http://news.cnet.com/Iridium-files-for-Chapter-11-bankruptcy/2100-1033_3-229816.html [URLs verified on September 22, 2013]

[10] http://www.airspacemag.com/space-exploration/iridium.html [URL verified on September 22, 2013]

[11] http://www.iridium.com

[12] http://www.bizjournals.com/sanjose/stories/2004/05/17/story6.html?page=all [URL verified on September 22, 2013]

[13] http://business.financialpost.com/2013/08/23/amazon-said-to-test-its-own-wireless-network-in-california/?__lsa=13b9-ab5d [URL verified on September 22, 2013]

[14] http://www.bloomberg.com/news/2013-08-23/amazon-is-said-to-have-tested-a-wireless-network.html [URL verified on September 22, 2013]

[15] http://www.prnewswire.com/news-releases/iridium-satellite-and-blue-sky-network-enhance-communications-for-aviation-customers-75611832.html [URL verified on September 22, 2013]

rate data services for specialized applications. As shown in Table 2-1, the broadband packages vary both by the broadband speed delivered and the monthly data allowance.[16]

Company	*Data Pricing*	*Download Speeds*	*Upload Speeds*	*Monthly Data Allowance*
HughesNet	$49.99 - 99.99	5 Mbps - 15 Mbps	1 Mbps - 2 Mbps	10 GB - 40 GB
ViaSat - Exede/WildBlue	$49.99 - $129.99	12 Mbps	3Mbps	10 GB - 25GB

Note 1: Service packages also require leasing/purchasing of CPE

Note 2: Additional charges apply if the customer exceeds the Monthly Data Allowance.

Table 2-1: Satellite Consumer Broadband Service Offerings

When comparing satellite broadband service offerings to landline based offerings, all of the satellite limitations described in Section 4 of this report must be considered. The satellite quality, performance, and reliability are not comparable to a modern landline system. The FCC has noted that current landline providers offer 150 GB to 250 GB of data use per month and stated, "We provide guidance by noting that a usage limit significantly below these current offerings (e.g., a 10 GB monthly data limit) would not be reasonably comparable to residential terrestrial fixed broadband in urban areas."[17] As shown in Table 2-1, these standard satellite offerings provide a significantly lower monthly data allowance than what is considered acceptable to the FCC. With these low monthly data usage allowances, users would quickly exhaust their monthly allocations with streaming video or other high-bandwidth applications.

[16] The information for Table 2-1 was derived from the HughesNet (www.hughesnet.com) and ViaSat (www.viasat.com) websites and was valid as of September 22, 2013.

[17] *Connect America Fund*, WC Docket No. 10-90, *A National Broadband Plan for our Future*, GN Docket No. 09-51, *Establishing Just and Reasonable Rates for Local Exchange Carriers*, WC Docket No. 07-135, *High-Cost Universal Service Support*, WC Docket No. 05-337, *Developing an Unified Intercarrier Compensation Regime*, CC Docket No. 01-92, *Federal –State Joint Board on Universal Service*, CC Docket No. 96-45, Lifeline and Link-Up, WC Docket No. 03-109, *Universal Service – Mobility Fund*, WT Docket No. 10-208, Report and Order and Further Notice of Proposed Rulemaking, FCC 11-161 (rel. November 18, 2011), pg. 36-37.

3 Industry Regulation

The transmission of services via satellite is regulated by the FCC and coordinated with the International Telecommunications Union (ITU). Federal regulations require that:

> No person shall use or operate apparatus for the transmission of energy or communications or signals by space or earth stations except under, and in accordance with, an appropriate authorization granted by the Federal Communications Commission.[18]

As part of its FCC review process, applicants must submit a comprehensive proposal including items such as the proposed frequencies to be utilized, operating specifications, orbit parameters and disposal plans.

Orbital separation of between two and three degrees is common for geostationary satellites. Because of this physical separation, there is a limit on the number of satellites that can be placed into orbit. There has been pressure for tighter regulations to ensure that the allocated slots are actually being used. For example, in 2012 the FCC reclaimed a slot from Dish. In that decision, the FCC stated that allowing Dish to keep the license "would allow Dish to warehouse scarce orbit and spectrum resources."[19] Demand for satellite orbital slots continues to grow. In 2008, Andrea Maleter, technical director at Futron Corp., stated:[20]

> …there are not any orbital slots currently unused or unspoken for (as in allocated to satellites already under construction and expected to launch in the near future) that provide access to what might be considered significant markets.

The FCC typically leaves an orbital slot vacant for 90 days, unless a waiver is granted.[21] Waivers are typically granted in the case of launch or in-orbit failures.

3.1 Frequency Utilization

To increase capacity, satellite providers must add more satellites, i.e. spatial diversity, or add more spectrum, i.e. frequency diversity.[22] Table 3-1 shows commonly utilized commercial communication satellite bands and their general characteristics.[23]

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[18] CFR Title 47, Part 25, Subpart A, Paragraph 25.102 Station authorization required.

[19] http://www.spacenews.com/article/dish-weighs-appeal-fcc-ruling-vacant-orbital-slot [URL verified on September 22, 2013]

[20] http://www.satellitetoday.com/publications/via-satellite-magazine/features/2008/03/01/hot-orbital-slots-is-there-anything-left/ [URL verified on September 22, 2013]

[21] CFR Title 47, Part 25, Subpart D, Paragraph 25.161 Automatic termination of station authorization.

[22] Wireless technologies employ a similar means to increase capacity. Instead of adding satellites, wireless companies add more towers. Additional spectrum increases capacity for both wireless and satellite.

[23] Table is adapted from "A Practical Introductory Guide on Using Satellite Technology for Communications", Intelsat, http://www.intelsat.com/wp-content/uploads/2013/01/5941-SatellitePrimer-2010.pdf pg. 5. [URL verified on September 22, 2013]

Band	Frequency	Characteristics	Applications
C	4 – 6 GHz	C-band transmissions are required to have lower power, since they share spectrum with terrestrial microwave. C-band satellite antennas or "dishes" are normally larger (4.5 to 18 meters in diameter) due to the lower frequency.	Public switched networks Internet trunking Broadcast Video
Ku	11 – 14 GHz	Smaller diameter satellite dishes can be used due to the higher frequency. The higher frequency of the Ku-band also makes it more susceptible to atmospheric propagation loss and adverse weather conditions than the C-band.	VSAT Rural telephony Satellite news gathering Videoconferencing Multimedia applications Broadcast Video
Ka	18 - 30 GHz	Smaller diameter satellite dishes can be used due to the higher frequency. Ka-band transmissions are impacted more by atmospheric propagation loss and poor weather conditions than the C-band or Ku-band.	High-speed Internet Videoconferencing Multimedia applications Broadcast Video

Table 3-1: Typical Commercial Communication Satellite Frequency Bands

3.2 Satellite Life Cycle

Satellites require active maneuvering to maintain their orbits. Satellite maneuvers consume the satellite's onboard fuel. As the fuel supply of a satellite dwindles, the operator must plan to decommission the satellite. The FCC requires that geostationary satellites launched after March 18, 2002 be disposed of at a specific altitude, referred to as the graveyard orbit.[24] This requirement keeps the geostationary orbit clear of non-operating satellites. After most of their fuel has been spent, some geostationary satellites are placed into inclined orbits to prolong their useful lives. When in an inclined orbit, the satellite is allowed to drift north and south, which requires less fuel to maintain the satellite. Since a satellite in an inclined orbit is no longer stationary, earth based ground stations must be able to track the satellite; therefore, satellites in inclined orbits are generally only used for military, aircraft, maritime, and other commercial applications.[25] LEO communication satellites are typically either actively de-orbited or allowed to have their orbit decay before re-entry into the atmosphere. If the satellite is large enough that it would not be completely consumed during re-entry, the operator maneuvers it to a predetermined impact area. NASA's *Orbital Debris Mitigation Standard Practices* contains guidelines for the disposal of satellites to limit the amount of debris released.[26]

[24] CFR Title 47, Part 25, Subpart D, Paragraph 25.283 End-of-life disposal.
[25] http://www.intelsatgeneral.com/service-offerings/satellite-bandwidth/inclined-orbit-capacity [URL verified on September 22, 2013]
[26] http://orbitaldebris.jsc.nasa.gov/library/USG_OD_Standard_Practices.pdf [URL verified on September 22, 2013]

4 Satellite Uses and Limitations

With the delivery of services from space, there are unique technology concerns that must be considered when evaluating satellite as a telecommunications platform. These concerns include communication channel limitations (such as capacity limitations, latency, and jitter), weather interference, terrestrial blockage, and sun interference. The industry has used various techniques to minimize the impacts of these impairments. Nevertheless, many of these impairments cannot be overcome because they are simply the result of the satellite's distance from the earth, the laws of physics, and other factors outside the control of the satellite operator. While satellite technology plays an important role for certain applications, satellite technology cannot approach the quality, capacity and utility of terrestrial-based technology when providing fixed location broadband services.

4.1 Satellite Communication Impairments

4.1.1 Latency

Latency is a measurement of the delay that occurs from the time a signal is sent to the time when it is received. In two-way communication systems, round trip latency is considered since each end must send and receive responses.

Satellite signals travel near the speed of light. Even at this speed, latency is an impairment to satellite communication due to the large distance the signals must travel. Figure 4-1 shows the calculation of the time for the satellite signal to travel from a ground station to a geostationary satellite. For this example, it is assumed that the satellite is directly over the equator, which would be the shortest distance from a satellite to a ground station.

$$Distance\ to\ Satellite \div Speed\ of\ Light = Time\ Delay$$

$$35{,}786\ km\ \div 300{,}000\ \frac{km}{s} = 120\ ms$$

Figure 4-1: Satellite Latency Calculation

Given that a signal must travel from a ground station to the satellite and back, in addition to normally experienced communications processing delays, the total delay for one-way communication between two ground stations is between 250 and 300 ms. For two-way communications, as when one satellite customer communicates with another satellite customer, the round-trip time would typically be between 500 and 600 ms. This "double-hop" scenario is likely for people who have satellite as their only communications option because they often live in close proximity with others that are served by satellite. Unacceptable communication delays would be experienced when calling a neighbor, friend, or local business that also uses satellite service, even though the two customers may be geographically close. Since this latency is primarily caused by laws of physics, there is no way to avoid it.

Voice and many data services are time-sensitive, or isochronous, in nature. Because of this characteristic, interactive voice and data communications are degraded when utilizing geostationary satellites. Specifically, latency limits subscribers from using some real-time applications, Virtual Private Networking (VPN) and online applications (such as Google Docs).[27] In the FCC's *2013 Measuring Broadband in America* report,[28] performance characteristics were compared. Regarding latency tests, the FCC stated that "ViaSat had a measured latency of 638 ms for this report, approximately 20 times that for the terrestrial average."[29] Hans Kruse explains the reason for high latency in his report, *Satellite Services for Internet Access in Rural Areas*:

> …a transmission over a satellite requires about ¼ of a second to travel from the sender to the receiver, due to the physical distance between the satellite and earth. TCP/IP relies on a complex system of queries and responses to determine an appropriate rate at which to send data. Too fast and the transmission overloads one or more links inside the network. Too slow, and the link is not used efficiently.…The transmission delay over a satellite link slows this convergence process down.[30]

While the physics that limit signal speed cannot be altered, technical improvements, such as protocol acceleration and information caching, reduce the number of times communication must occur between the earth-based systems and the satellite thus minimizing the effects of latency. Regarding these techniques, the FCC stated:

> ViaSat and other satellite industry operators have lowered overall latency by making improvements to other elements of their architecture, such as by dispensing with the need to request communication channel assignments, adopting advances in consumer satellite terminal equipment, incorporating protocol acceleration technology, and developing new error correction technology to provide resiliency to rain fade. Despite these many improvements, latency for this new generation [of] satellite-delivered broadband remains high. [31]

As discussed previously, LEO satellites have been deployed to help minimize latency problems, but this technology requires a sophisticated constellation of satellites and complex customer equipment. Thus, this technology is even more expensive than geostationary satellites.

4.1.2 Terrestrial Blockage

Since geostationary satellites orbit the earth over the equator, subscribers at the equator point their satellite dishes nearly straight up to communicate with the satellite. As a subscriber's distance from the equator increases, the elevation of the dish relative to the horizon decreases. [32] Therefore, the

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[27] http://www.rumbausa.net/downloads/rumba-satellite-wp-press.pdf [URL verified on September 22, 2013]
[28] http://www.fcc.gov/measuring-broadband-america/2013/February
[29] ViaSat primarily offers their satellite services to consumers.
[30] http://www.its.ohiou.edu/kruse/publications/Satellite%20Internet.pdf [URL verified on September 22, 2013]
[31] Measuring Broadband in America, pg. 14.
[32] The angle of the dish relative to the horizon is referred to as the dish elevation.

likelihood of an object obscuring the direct view of a satellite also increases as the subscriber's distance from the equator increases, as shown in Figure 4-2. Thus, terrestrial blockage is a more significant issue in the northern states than in the southern states.

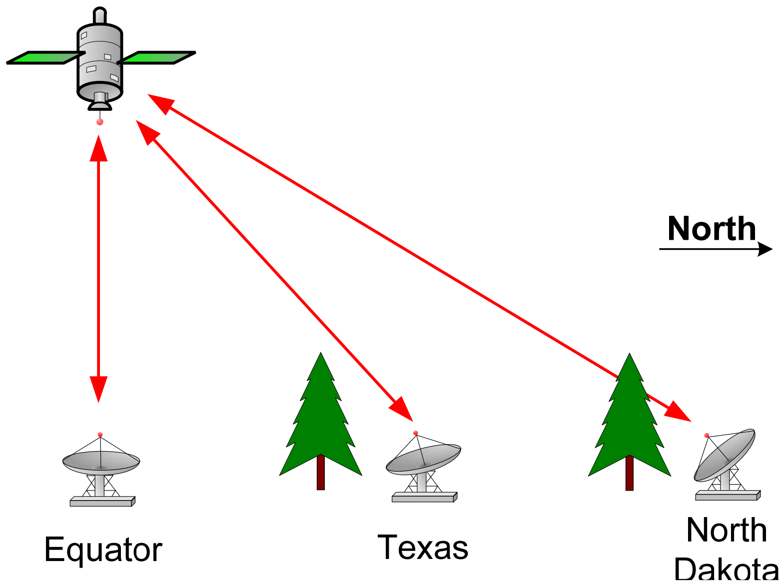

Figure 4-2: Satellite Dish Elevation

4.1.3 Weather Interference

Weather can also affect the reliability of satellite communications. The frequencies used by satellite systems are susceptible to weather degradation. Transmission errors can be caused by heavy rain and the accumulation of ice or snow on dishes.[33] Weather interference occurs more severely in northern areas of the United States where there are lower dish elevations, since the signals must travel a greater distance through the atmosphere before reaching the satellite.

To mitigate weather effects, satellite providers have implemented adaptive power control and more robust modulation techniques; however, weather interference problems persist.[34] Such problems have caused some application providers to issue warnings to their customers who utilize satellite-based broadband. For example, *Let's Go Learn*, a student assessment company, warns:[35]

[33] http://www.its.ohiou.edu/kruse/publications/Satellite%20Internet.pdf [URL verified on September 22, 2013]
[34] Mitigating the Effect of Weather on Ka-band High-Capacity Satellites, Jim Petravonivich, March, 2012 pg. 8.
[35] http://www.letsgolearn.com/lglsite/support_read/known_issues_with_satellite_internet/ [URL verified on September 22, 2013]

Support Home / Known Issues with Satellite Internet

Known Issues with Satellite Internet

If you are using Hughs, Wild Blue, or another satellite internet service provider, please take note.

Please schedule your student assessments when there are NO storms in your area. Adverse weather can cause intermittent connection issues with your internet service provider, which may affect your student testing.

Recently, we had students with invalid *DORA* assessment scores because our servers were not receiving their responses. All of the assessments that Let's Go Learn provides employ proprietary adaptive logic. If we do not receive all of the students' responses or receive partial responses, our adaptive logic will not work properly.

If you feel that your student's assessment was affected by this issue, please call our customer support at 1-888-618-7323 or email us at help@letsgolearn.com.

Figure 4-3: Customer Support Warning

4.1.4 Sun Interference

Twice a year the sun crosses behind each geostationary satellite as it is viewed from the ground station. During these periods in the spring and fall, the alignment of thermal noise from the sun with the satellite signals causes a temporary loss of signal. The duration of the outage depends on the satellite ground station location, satellite orbital location, size of the antenna, and the signal frequency.[36] Many publicly available calculators predict solar outages. Figure 4-4 shows an example solar outage prediction for Minneapolis, Minnesota with the ViaSat-1 satellite, Ku frequency band, and a 30-inch dish for a week during October.[37]

[36] http://www.intelsat.com/tools-resources/satellite-basics/satellite-sun-interference/ [URL verified on September 22, 2013]

[37] Prediction was performed with this calculator: http://www.satellite-calculations.com/Satellite/suninterference.php [URL verified on September 22, 2013]

Satellite name: VIASAT-1 Satellite Position: 115.1 °W (244.9 °E) Location: 6925 34th Avenue South, Minneapolis–Saint Paul International Airport (MSP), Minneapolis, MN 55450, USA Coordinates: 93.218 °W 44.8802 °N Altitude: 251.46 [m] 824.99 [feet] Antenna Size=0.76 [m] Frequency=11.95 [GHz]								
Start Interference UTC mm/dd/yyyy hh:mm:ss	End Interference UTC mm/dd/yyyy hh:mm:ss	Peak Interference UTC mm/dd/yyyy hh:mm:ss	Start Interference UTC-5h mm/dd/yyyy hh:mm:ss	End Interference UTC-5h mm/dd/yyyy hh:mm:ss	Peak Interference UTC-5h mm/dd/yyyy hh:mm:ss	Duration Time hh:mm	Min. Separation Degrees	Peak CN Degradation [dB]
10/06/2013 19:36:02	10/06/2013 19:41:13	10/06/2013 19:38:37	10/06/2013 14:36:02	10/06/2013 14:41:13	10/06/2013 14:38:37	05m11s	1.309	2.6
10/07/2013 19:33:49	10/07/2013 19:42:51	10/07/2013 19:38:20	10/07/2013 14:33:49	10/07/2013 14:42:51	10/07/2013 14:38:20	09m02s	0.927	3.5
10/08/2013 19:32:38	10/08/2013 19:43:28	10/08/2013 19:38:03	10/08/2013 14:32:38	10/08/2013 14:43:28	10/08/2013 14:38:03	10m50s	0.546	4.3
10/09/2013 19:31:59	10/09/2013 19:43:35	10/09/2013 19:37:47	10/09/2013 14:31:59	10/09/2013 14:43:35	10/09/2013 14:37:47	11m36s	0.167	4.7
10/10/2013 19:31:44	10/10/2013 19:43:18	10/10/2013 19:37:31	10/10/2013 14:31:44	10/10/2013 14:43:18	10/10/2013 14:37:31	11m33s	-0.21	4.7
10/11/2013 19:31:55	10/11/2013 19:42:37	10/11/2013 19:37:16	10/11/2013 14:31:55	10/11/2013 14:42:37	10/11/2013 14:37:16	10m42s	-0.59	4.2
10/12/2013 19:32:37	10/12/2013 19:41:24	10/12/2013 19:37:01	10/12/2013 14:32:37	10/12/2013 14:41:24	10/12/2013 14:37:01	08m47s	-0.96	3.4
10/13/2013 19:34:24	10/13/2013 19:39:08	10/13/2013 19:36:46	10/13/2013 14:34:24	10/13/2013 14:39:08	10/13/2013 14:36:46	04m43s	-1.34	2.5

Figure 4-4: Example Sun Outage Prediction

The calculator predicts that several days will have outages exceeding ten minutes in duration. As user antennas become smaller, outages normally become longer. Outages lasting 15 minutes or longer in a single day are common. These solar outages make geostationary satellites a poor choice for most data that requires extremely high availability and reliability. These outages also are problematic for subscribers who need to dial 911 or other emergency services.

4.2 Voice over Satellite Concerns

The use of satellite communications for voice services creates Quality of Service (QoS) challenges. There are both quantitative and qualitative parameters that can be evaluated for satellite-based voice services.

4.2.1 Quantitative QoS Metrics

Packet loss, traffic prioritization, compression technologies and bandwidth all contribute to the overall quality of a satellite Internet Protocol (IP) call. The primary QoS measurements are latency and jitter, of which latency is the primary barrier to quality satellite-based voice communications. Regarding the impact latency has on users' experience, the FCC stated in *OBI Technical Paper No. 1* ("OBI No. 1"):[38]

> …latency associated with satellite would affect the perceived performance of applications requiring real-time user input, such as VoIP and interactive gaming. Not only does this delay have a potentially noticeable effect on applications like VoIP, but it would also be doubled in cases where both users were using satellite broadband (e.g., if two neighbors, both served by satellite VOIP, talked on the telephone). Given that most voice calls are local, this could become a significant issue for rural areas if all calls must be completed over satellite broadband.

ITU-T Recommendation G.114 specifies a maximum round-trip latency threshold of 300 ms for acceptable voice services. As shown in Section 4.1.1, the round-trip latency for satellite signals is between 500 and 600 ms—twice the allowable threshold. With this level of latency, the quality of service leads to a poor user experience, as discussed below.

Packet loss or packet corruption also causes degradation of voice quality. Therefore, if packets are lost due to congestion, weather interference, or other issues, the voice quality will suffer greatly. Because of satellite susceptibility to these issues, the use of satellite as a replacement for traditional landline service (or terrestrial wireless) for voice communications is not desirable, especially when the service involves 911 and other critical services.

4.2.2 Qualitative QoS Measurements

Ultimately, subscribers' perception of the service will be largely driven by their experiences. For example, was the call prompt, clear, and hassle-free? The perception of quality can be measured using a subjective rating called the Mean Opinion Score (MOS). Like most standards, this standard is interpreted differently within the vendor community.[39] Nevertheless, MOS scores are generally categorized and defined in ITU-T Recommendation P.800 as depicted in Table 4-1.

MOS	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible, but not Annoying
3	Fair	Slightly Annoying
2	Poor	Annoying
1	Bad	Very Annoying

Table 4-1: MOS Score Definition

[38] http://download.broadband.gov/plan/the-broadband-availability-gap-obi-technical-paper-no-1-chapter-4-network-economics.pdf [URL verified on September 22, 2013]

[39] ITU-T Recommendation P.800 defines the environment that a person would use to listen and score a voice call. Since it is difficult to actually measure (and score) a subjective measure of quality, the ITU-T released a new specification – PESQ P.862 as the standard to calculate and score voice quality.

The standard for comparison is the traditional wired landline TDM voice circuit. Generally, a MOS score for TDM voice calls average above 4.0,[40] while satellite calls have much lower scores. PhonePower, a VoIP service provider, has performed an analysis of MOS and other parameters that affect voice quality over various networks.[41] PhonePower's analysis shows satellite VoIP providers have MOS scores below 1.5. Regarding this result, PhonePower states that "this reinforces what most of us knew; which is satellite and indirect wireless connections are less capable of producing usable VoIP quality." As shown in Figure 4-5, satellite providers, such as Hughes Network Systems and WildBlue Communications, have VoIP service classified as "Very Annoying" using the MOS scale.[42]

4.2.3 Satellite Voice Customer Premises Equipment

Satellite voice Customer Premises Equipment (CPE) has made great strides over the last decade. Earlier satellite phone models were large, briefcase-sized consoles, while newer models are much smaller. Even so, a typical satellite phone in use today is approximately twice the weight and five times as thick as an iPhone. Unlike smart phones, satellite phones today do not support Internet Access or other data plans. Moreover, the cost of a satellite phone typically ranges from $499 to $899 depending upon battery life, size and other factors.

[40] Most TDM scores are in the range of 4.1 to 4.3.

[41] http://www.phonepower.com/blog/2011/11/01/the-internet-through-phone-power-colored-glasses/ [URL verified on September 22, 2013]

[42] WildBlue Communications and Hughes Network Systems have MOS scores of 1.

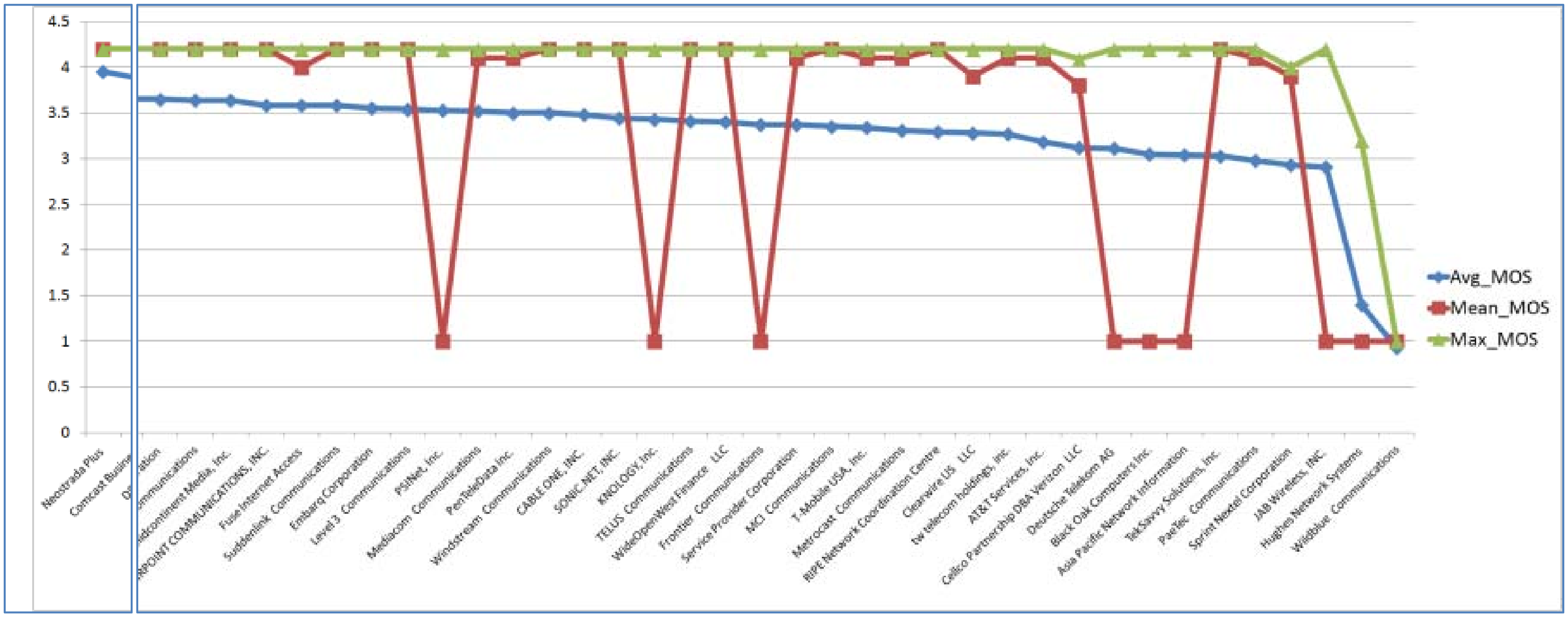

Figure 4-5: MOS Scores for Various Service Providers[43]

[43] http://www.phonepower.com/blog/2011/11/01/the-internet-through-phone-power-colored-glasses/ [URL verified on September 22, 2013] Note: To make the information more viewable, only a portion of the overall graph is shown in the figure.

4.3 Broadband over Satellite Concerns

Satellite capacity limitations remain a constraint on broadband deployment. Since both orbital slots and additional spectrum are scarce commodities, satellite manufacturers have started to use spot beams as a form of spatial diversity. Rather than one large CONUS beam, covering the continental United States, spot beams are targeted to specific coverage areas. Spot beams enable large-scale frequency re-use,[44] which allows subscribers to be served more efficiently and directs capacity to where it is needed most. Figure 4-6 compares CONUS beam coverage with spot beam coverage.[45]

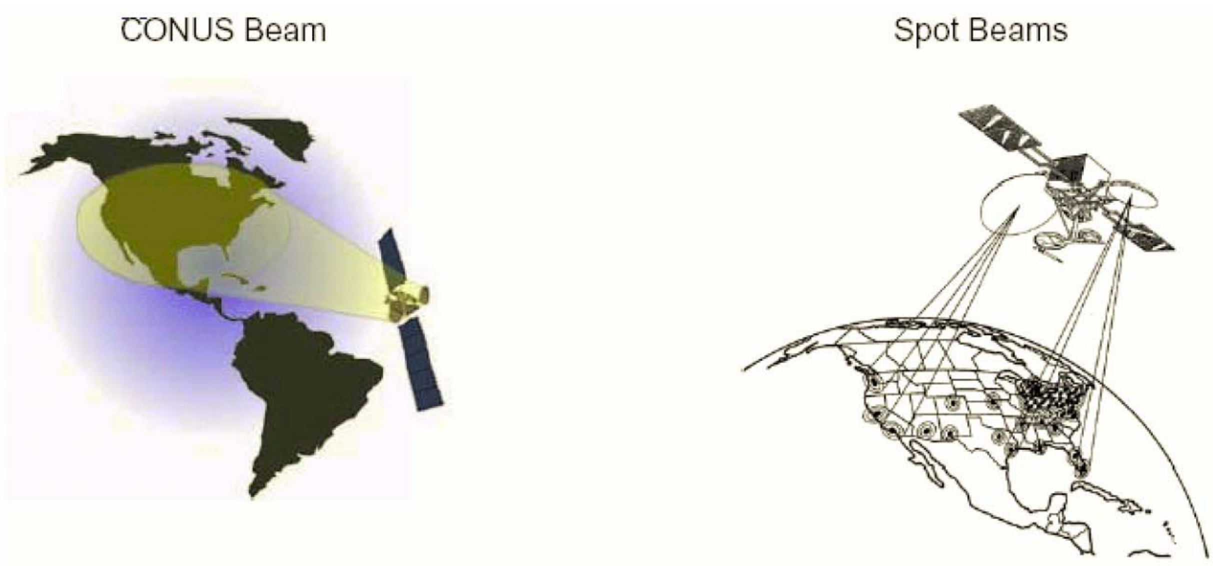

Figure 4-6: Spot Beam

ViaSat states that its latest generation satellite, ViaSat-1, has a throughput capacity of 134 Gbps.[46] The ViaSat-2 satellite, scheduled for launch in 2016, is thought to utilize ground-based beam forming (GBBF) technology.[47] ViaSat claims that a GBBF system can coordinate and process up to 500 beams at once. ViaSat identifies the following benefits of a GBBF system:

- Faster and lower cost satellite deployment because the processing is on the ground, rather than part of the satellite bus;
- Ability to coordinate frequency use and remove interference for mass numbers of subscribers; and

[44] Mitigating the Effect of Weather on Ka-band High-Capacity Satellites, Jim Petravonivich, March, 2012 pg. 1.
[45] http://www.satelliteone.com/support-files/Spot_Beam_Short.pdf [URL verified on September 22, 2013]
[46] ViaSat claims that ViaSat-1 is the highest capacity satellite in the world.
[47] http://www.satellitetoday.com/telecom/2013/05/17/boeing-surprise-winner-of-viasat-2-deal/ [URL verified on September 22, 2013]

- Refocusing of satellite capacity to the areas of greatest need.[48]

These advancements are reported to allow ViaSat-2 to double the throughput capacity of ViaSat-1, but these advancements are expensive. The ViaSat-2 satellite is anticipated to cost approximately $625 million, approximately 25 percent more than ViaSat-1.[49]

With its new ViaSat-1 satellite, ViaSat believes it will be able to offer 12 Mbps download service to approximately one million subscribers.[50] If the one million subscribers attempted to access the satellite at the same time, each subscriber could receive only 134 Kbps. Since only 134 Gbps is available on the entire satellite, offering 12 Mbps to one million subscribers results in an oversubscription ratio of approximately 90:1.[51] In other words, the total capacity sold to the customers is 90 times more than what is available on the satellite. Unless satellite customers' broadband consumption is significantly restricted, an oversubscription ratio of 90:1 would cause performance issues. For example, less than three percent of the one million households could watch a single Netflix HD movie before the entire satellite capacity is exhausted.[52]

To maximize the number of served subscribers, most satellite broadband packages have monthly bandwidth capacity limits.[53] Data intensive applications, such as streaming content, online back-ups, video conferencing and downloading of large files, can cause subscribers to quickly exceed these monthly capacity limits. Other applications that are extremely data intensive, such as telepresence and some medical and educational applications are not even practical. The FCC in OBI No. 1 analyzed the satellite industry's capacity to provide broadband services. The FCC evaluated the busy hour offered load ("BHOL") of the network and estimated that with a "medium usage" case the satellite industry could support approximately one million subscribers by 2015. Concerning this result, the FCC stated:

> Given that the satellite industry in the United States currently supports roughly 900,000 subscribers, this presents a potential difficulty in meeting the needs of the industry's current subscriber base, plus new net additions. If satellite broadband is offered at a level of service comparable to that of terrestrial broadband under the "medium usage" case and BHOL growth continues, satellite providers will need to devote significant incremental capacity to their existing customer base.

[48] http://www.viasat.com/advanced-technology/comsat-labs-technology-and-product-development [URL verified on September 22, 2013]

[49] http://www.spacenews.com/article/satellite-telecom/35369viasat-2s-first-of-its-kind-design-will-enable-broad-geographic-reach [URL verified on September 22, 2013]

[50] http://www.viasat.com/broadband-satellite-networks/high-capacity-satellite-system [URL verified on September 22, 2013]

[51] Selling 12 Mbps to one million subscribers means that ViaSat would be selling a total of 12 Tbps.

[52] Netflix recommends 5 Mbps broadband for an HD movie as show on their support website at: https://support.netflix.com/en/node/306 [URL verified on September 26, 2013]

[53] For example, WildBlue's bandwidth capacity policy: http://www.wildblue.com/customers/data-allowance-policy [URL verified on September 22, 2013]

Even though the FCC recognized the difficulty of satellites meeting subscriber broadband needs, this difficulty is underestimated. While the authors of the OBI No. 1 note that an average BHOL of 444 Kbps would be required for users to achieve burst speeds of 4 Mbps.[54] Instead of designing a network capable of accommodating 444 kbps, the FCC assumed a BHOL of 160 kbps because service providers can use management techniques to mitigate the impact of heavy users.[55] To make this assumption, the usage of the heaviest ten percent of users was disregarded, even though these heavy users' usage represents 65 percent of the network load.[56] While management techniques can mitigate the impact of heavy users, reducing the assumed BHOL percent to 160 kbps would significantly reduce the probability of a customer achieving 4/1 Mbps broadband. Removing the heaviest users under the assumption that their traffic will be throttled runs counter to the goal of providing quality, ubiquitous broadband service.

Even though a BHOL of 160 Kbps is insufficient to provide 4/1 Mbps broadband, satellite providers typically deliver a much lower service standard. The OBI No. 1 notes that older satellites offer a BHOL of between five and ten Kbps and newer high-capacity satellites are provisioned for a BHOL of between 30 and 50 Kbps.[57] A BHOL of 50 Kbps is three times less than the FCC's BHOL estimate of 160 Kbps and nine times less than the 444 Kbps BHOL required for 4/1 Mbps service if the heaviest users are not omitted or severely throttled.

In addition to underestimating the assumed BHOL, the OBI No.1 did not appear to consider the impact of the communications contention algorithms utilized by most satellite providers. Contention algorithms define how the satellite transmitters respond when two users transmit at the same time. Many satellite systems utilize ALOHA or Slotted ALOHA to handle contention. The basic premise of ALOHA is that if a data collision occurs, senders will wait a random amount of time before resending. But as more users are added to the network, the process becomes less efficient and throughput decreases. Slotted ALOHA improved the process by defining specific timeslots that data retransmission can be attempted. Figure 4-7 shows how the network throughput decreases as the number of subscribers increases.[58] The contention algorithms and protocols used by the newer satellites are not readily available. Since these protocols could result in a satellite's actual capacity being significantly lower than the satellite's advertised capacity, the FCC should investigate the actual satellite capacity when the contention algorithms and protocol overheads are considered.

[54] OBI No. 1, Exhibit 4-BS, p. 113.
[55] Id., p. 111.
[56] Id., p. 111.
[57] Id., p. 91.
[58] WildBlue placed a moratorium on new service installations. This moratorium was likely the result of capacity issues.

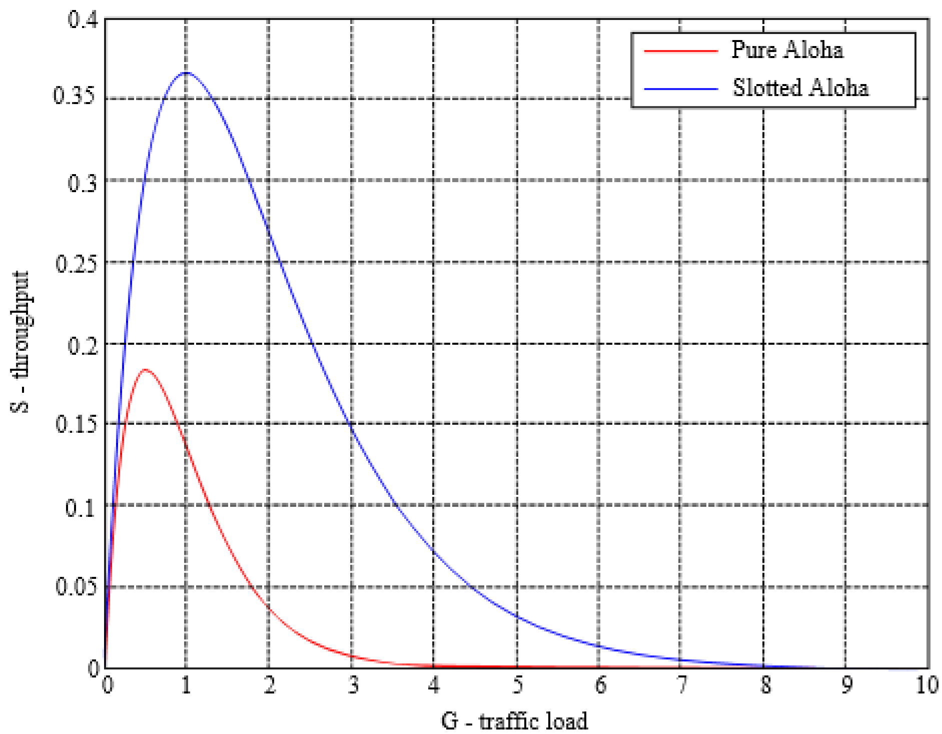

Figure 4-7: ALOHA Protocol Capacity versus Traffic Load[59]

4.4 Terrestrial and Celestial Broadband Comparison

As described in previous sections of this report, satellite-based communication networks have significant limitations as compared to wireline communications networks. Since FTTP networks do not suffer from many of the impairments experienced by satellite networks, such as weather effects, solar outages, and high latency, the mix of features and services available on a FTTP network (voice, video, and broadband data) is more robust. Table 4-2 compares these technologies.

Technology	***Latency***	***Weather Interference***	***Bandwidth Capacity Limitations***
Satellite	Very high, making many real-time applications unusable	Susceptible to weather interference, especially higher frequency bands (which are being used by new higher capacity satellites)	Shared bandwidth on the satellite platform. Limits on the number of satellites that can be placed in orbital slots.
FTTP	Negligible	Service Unaffected	Virtually None

Table 4-2: Service Offering Limitations Comparison

[59] http://en.wikipedia.org/wiki/File:Aloha_PureVsSlotted.svg [URL verified on September 22, 2013]

FTTP network architectures provide much greater bandwidth per customer than satellite technology. For example, Gigabit Capable Passive Optical Network ("GPON") is a commonly deployed FTTP technology. GPON can provide 2.5 Gbps of capacity to each grouping of up to 32 customers, or more than 70 Mbps per customer. Thus, GPON can provide 500 times more capacity than the 134 Kbps per customer calculated earlier for the ViaSat 1 satellite. The next generation of FTTP electronics, being standardized as "NG-PON2" will have a capacity of 40 Gbps, or 1.25 Gbps per customer assuming all customers share the capacity equally.[60] Additionally, Active Ethernet technology has increasingly become an economical solution and is becoming more widely deployed in fiber networks. With Active Ethernet solutions, 1 Gbps symmetrical service is possible per customer. Even though recent advances have increased satellite capacity, the capacity available to a customer using satellite broadband technologies is much smaller than what is available over a single fiber. Regardless, shared capacity systems, such as satellites, are not well suited for constant bit rate traffic, such as video, that is prevalent on today's networks.

[60] NG-PON2 is expected to be generally available in 2015.

About the Authors

Larry Thompson is a licensed Professional Engineer and CEO of Vantage Point Solutions. Larry has a Physics degree from William Jewell College and a Bachelor's and Master's degree in Electrical Engineering from the University of Kansas. He has been working in the telecommunications industry for more than 25 years, which has included both satellite and ground station design and engineering in the 1 to 30 GHz range. Larry was on the engineering team for the Tracking and Data Relay Satellite System (TDRSS), Geostationary Environmental Orbital Satellite (GOES) ground station, T-Star, and other satellite systems. Larry has helped hundreds of rural telecommunication companies be successful in this rapidly changing technical and regulatory environment. He has designed many wireless and wireline networks as he as assisted his clients in their transition from legacy TDM networks to broadband IP networks.

Brian Enga is a licensed Professional Engineer and part of the Senior Engineering team at Vantage Point Solutions. Brian has a Bachelor's of Science degrees in Electrical Engineering and Engineering Physics from South Dakota State University. He has been working in the telecommunications industry for more than 15 years. Brian has engineered a variety of landline and wireless networks and has been a pioneer in deploying IP video networks.

March 10, 2015

***Ex Parte* Notice**

Ms. Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

RE: Re: *Connect America Fund*, WC Docket No. 10-90; *High-Cost Universal Service Support*, WC Docket No. 05-337

Dear Ms. Dortch:

As the Federal Communications Commission (the "Commission") continues to implement a cost model to distribute universal support for price-cap regulated carriers, assesses whether some form of model might be made available on a voluntary basis for support of rate-of-return-regulated local exchange carrier ("RLEC") investment and operations, and evaluates the extent to which there may be an alleged competitive presence in specific geographic areas, NTCA–The Rural Broadband Association ("NTCA") submits the enclosed technical paper by Vantage Point Solutions – "Wireless Broadband is Not a Viable Substitute for Wireline Broadband" – into the record of the above-referenced proceedings to aid in consideration of each of these questions.

By way of background, the Communications Act establishes a national policy that the Commission promote the availability of both "radio and wire communication service." 47 U.S.C. § 151. Developments in recent years, particularly as broadband services evolve and consumer demands for bandwidth increase, only highlight the enduring complementary nature of wireline and wireless services in fulfilling consumer expectations and needs. *See, e.g.*, Prepared Remarks of Chairman Tom Wheeler, "The Facts and Future of Broadband Competition," 1776 Headquarters, Washington, D.C. ("Wheeler Remarks") (Sept. 4, 2014), at 5.

NTCA members are full-service operators with substantial experience in leveraging both wireline and wireless technologies. While NTCA's members are RLECs, more than half of the member respondents to NTCA's 2014 Wireless Survey indicated that they hold spectrum below 2.3 GHz, with 71% of those having a 700 MHz license. NTCA 2014 Wireless Survey Report, December 2014, at 5-6. As these data make clear, in serving some of the most difficult terrain and sparsely populated areas in the United States, NTCA members and other RLECs have demonstrated their interest in leveraging a variety of technologies to respond to consumer demand and extend quality services to as many as possible. As the attached technical paper underscores, however, it is essential to take accurate stock of the capabilities and limitations of various technologies in devising scalable broadband network solutions and to fashion policy based on an in-depth technical evaluation of the true substitutability of one technology platform versus another as part of achieving and sustaining universal service.

In particular, as the paper demonstrates from a technical perspective, fiber-based wireline solutions represent the optimal path for establishing networks that are capable of efficient scaling to meet consumer demand for faster broadband speeds. *See also* Wheeler Remarks, at 5 ("Once fiber is in place, its beauty is that throughput increases are largely a matter of upgrading the electronics at both ends, something that costs much less than laying new connections.") To be clear, wireless networks are useful and important in providing a complementary service to that capable of being provided by a fiber-based wireline network. Yet, as the paper properly points out, particularly over time, wireline networks represent the critical foundation for more robust and scalable fixed broadband solutions that can ensure universal service.

Thank you for your attention to this correspondence. If you have any questions, please do not hesitate to contact the undersigned.

Sincerely,

/s/ *Michael R. Romano*
Michael R. Romano
Senior Vice President – Policy

Wireless Broadband is Not a Viable Substitute for Wireline Broadband

March 2015

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1 Executive Overview

High-quality broadband has become an essential service in both urban and rural areas of the United States. In places where broadband is available, the Federal Communications Commission ("FCC") has shown that urban and rural users adopt broadband at the same rate.[1] Education, healthcare, banking, entertainment, and many other industries rely on broadband to deliver their services. As new applications and services are developed, the broadband demands for both residential and commercial consumers continue to increase rapidly. Today, broadband providers offer their services using a variety of networks based on either landline or wireless technologies. However, not all broadband delivery technologies have the same capabilities. The differences in these technologies' capabilities affects the networks' ability to deliver broadband. This paper analyzes terrestrial wireless technologies' ability to deliver current and future broadband services.[2]

To properly compare and contrast various broadband delivery networks, it is first necessary to understand the characteristics of a good broadband connection. A high-quality broadband connection can be characterized by the following:

- High Speed – The network must deliver data at a fast rate
- Low Latency – The network must have a minimal amount of delay
- High Capacity – The network must deliver a "quantity" of data that meets customers' needs
- High Reliability – The network needs to experience few outages
- Economical and Scalable – The network must be cost effective to deploy, maintain, and upgrade as broadband demand increases

There are several factors that limit a wireless network's broadband quality which do not impact wireline broadband networks. Specifically, lack of spectrum limits both speed and capacity. In addition, weather and obstacles, such as terrain, attenuate the wireless signal thus limiting availability and reducing reliability. Finally, the speed of the network is a function of the number of users and the proximity of those users to the wireless tower.[3] These factors keep wireless technologies from being economically scalable to higher broadband speeds.

A primary factor limiting the broadband speed that a wireless network can provide is the amount of spectrum available. The largest wireless carriers, with all of their financial resources, hold less than 130

[1] *In the Matter of Connect America Fund et al.*, *Report and Order*, WC Docket Nos. 10-90, 14-58 and 14-192, FCC 14-190, released December 18, 2014 ("*CAF Phase II Order*") at ¶ 17.

[2] Broadband satellite systems were analyzed in detail previously. Vantage Point Solutions "Analysis of Satellite-Based Telecommunications and Broadband Services" http://apps.fcc.gov/ecfs/document/view?id=7520956711 Accessed November 14, 2014.

[3] The speed is slower as more users are added and an individual user's speed is slower the farther the user is from the tower.

MHz of spectrum in most market areas.[4] For example, Verizon currently has on average 116 MHz of spectrum nationwide.[5] Even with this amount of spectrum, all of the following assumptions must be true to reliably deliver what appears to be a target for broadband speed in the future — 100 Mbps:

- The wireless carrier would need to dedicate its entire spectrum to broadband; thus existing customers, including mobile customers, could not use this spectrum.
- The wireless carrier would need to rely on technologies that are not yet available to bond all their bands together, since their existing spectrum is in non-contiguous bands at different frequencies.
- Many towers must be constructed because it would only take a few customers to exhaust an entire tower's available capacity.

Obviously, these assumptions are unrealistic. Existing wireless customers could not just be abandoned to provide high-speed broadband. Wireless carriers cannot rely on technologies that are not yet commercially available. Finally, constructing a wireless network with many towers, along with the associated other costs such as backhaul, could prove to be cost prohibitive.

Many factors influence the cost to deploy a wireless network, including terrain, spectrum frequency band, spectrum quantity, and land costs. As this paper will show, the cost to deploy a wireless network increases dramatically as the broadband requirements increase. In contrast, wireline networks, especially those with fiber optics, are much better suited to economically deliver high-quality broadband. The relative cost of the two types of networks can be demonstrated by calculating the cost per megabit per second ("Mbps") delivered to the customer. Modern wireline networks rarely cost more than $10 per Mbps and often are less than $5 per Mbps, while it is common for a wireless network to cost several hundred dollars per Mbps. Later in this paper the cost for both a wireline and wireless broadband network is estimated for a specific service area.

As the number of users on the network increases and their usage grows at a rapid rate, wireless providers can address the bandwidth challenge in a variety of ways. CTIA-The Wireless Association ("CTIA") recently identified that carriers must "make choices regarding how to manage network resources" as customers' broadband needs increase.[6] Managing network resources means imposing stricter capacity limits. From a technical perspective, carriers can obtain more spectrum, use spectrum more efficiently or build more towers to meet customer's increased broadband needs. Given that spectrum is a limited resource, expensive for a wireless carrier to secure and uncertainties remain as to how much and when additional spectrum will be made available, wireless carriers must ensure that spectrum is used efficiently. While advances continue to be made in technology, current 4G LTE is

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[4] FCC PN January 30, 2015 DA 15-131 The AWS-3 – Auction 97 closed Jan. 29th, 2015 shows AT&T, Verizon and T-Mobile as provisionally winning bids in several markets – potentially increasing their spectrum depth by up to 30 MHz if approved.

[5] http://www.telecompetitor.com/verizon-use-lte-unlicensed-bands-boost-downlink-capacity/ as of November 14, 2014.

[6] Accessed December 10, 2014. http://apps.fcc.gov/ecfs/document/view?id=60000871627, p 2.

nearing the theoretical limit of spectral efficiency. Without additional spectrum or the ability to make that spectrum deliver significantly higher speeds, wireless carriers are building more towers with fiber optic backhaul to meet the broadband needs of their customers. In effect, wireless networks are incorporating landline technologies into their networks because of the wireline network's ability to offer higher broadband transport capacity at a lower cost. Even CTIA recognizes the limitations of wireless technologies when it stated that "even if we were able to get all the spectrum available in the U.S., we still wouldn't be able to have the same capacity as a single strand of fiber."[7]

The FCC has recognized that fiber is the only technology capable of meeting long-term broadband needs.[8] Today, most landline networks contain a significant amount of fiber and some are entirely fiber. FCC Chairman Tom Wheeler has also recognized the premier benefits of fiber in meeting broadband needs when he stated, "In the end, at this moment, only fiber gives the local cable company a competitive run for its money. Once fiber is in place, its beauty is that throughput increases are largely a matter of upgrading the electronics at both ends, something that costs much less than laying new connections."[9]

Wireline and wireless networks both play important roles in meeting customers' needs. Wireless networks are needed for low bit rate mobile applications, such as voice, email and small screen video. In contrast, wireline networks are required to meet customers' high speed, fixed broadband needs. As demonstrated in this report, for most customers, wireless technologies will not be a replacement for, but rather a complement to wireline broadband technologies.

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[7] *See, e.g.,* An Open Letter to the USA Today Editorial Board from CTIA Aug. 19, 2010): ("You've heard us say that wireless is different. Due to the science and physics of spectrum use, there is only so much capacity that is available. This differs dramatically from landline and cable broadband service. One strand of fiber has more capacity than the entire electromagnetic spectrum. So even if we were able to get all the spectrum available in the U.S., we still wouldn't be able to have the same capacity as a single strand of fiber."), available at: http://blog.ctia.org/2010/08/19/an-open-letter-to-the-usa-today-editorial-board/ (accessed Feb. 4, 2015); Mobile Future: Today's Wireless is Open Innovating and Different ("a *single* strand of broadband fiber has 2,000 times the capacity of **all** mobile spectrum") (emphasis in original), available at: http://mobilefuture.org/resources/todays-wireless-is-open-innovating-and-different/ (accessed Feb. 4, 2015).

[8] The Broadband Availability Gap, OBI Technical Paper No. 1, Federal Communications Commission, April 2010, p. 65.

[9] "The Facts and Future of Broadband Competition," Speech of Chairman Tom Wheeler, Federal Communications Commission, 1776 Headquarters, Washington, D.C., Sept. 4, 2014.

2 Public Funds Should be Invested in the Best Broadband Technologies

The FCC has established a new focus for universal service in the United States – to encourage the deployment of networks that can provide scalable broadband services. Due to customer demand, the speed at which broadband is provided has been steadily increasing. The FCC originally established minimum broadband requirements of 4 Mbps downstream and 1 Mbps upstream.[10] In December 2014, the FCC announced and adopted changes that require companies receiving funding from the Connect America Fund ("CAF") for fixed broadband services to provide 10 Mbps downstream and 1 Mbps upstream for any new facilities. The FCC said that this change is, ". . . an increase reflecting marketplace and technological changes that have occurred since the FCC set its previous requirement of 4 Mbps/1 Mbps speeds in 2011."[11] On February 4, 2015, the FCC increased the nation's definition for "advanced telecommunications capability" to 25 Mbps for downloads and 3 Mbps for uploads, while leaving minimum CAF requirements in place.[12] With the rapid increases in broadband demand, it is important to invest in networks and technologies that can not only deliver the broadband required today, but also deliver the broadband of tomorrow without major upgrade expenditures.

2.1 Broadband is Rapidly Becoming the 'Essential Service'

Higher speed requirements for Internet applications[13] and an increasing number of devices connected to the Internet are driving the demand for increased Internet speeds. As FCC Chairman Tom Wheeler recently observed, "A 25 Mbps connection is fast becoming 'table stakes' in 21st century communications."[14] Today, the vast majority of urban households have access to 25 Mbps connections or higher.[15] Consumers increasingly rely on broadband-intensive applications for education, remote healthcare, video communications, and entertainment. Rather than simply communicating by voice services alone, consumers are using broadband intensive services such as video streaming, video conferencing and other multi-media. According to the U.S. Internet Industry Association, ". . . the

[10] *In the Matter of Connect America Fund, et al.*, *Report and Order and Further Notice of Proposed Rulemaking*, WC Docket No. 10-90 *et al.*, 26 FCC Rcd 17663 (2011), *aff'd* In Re: FCC 11-161, 753 F.3d 1015 (10th Cir. 2014), *pet. for cert. pending* ("*USF/ICC Transformation Order*") at ¶ 22.

[11] FCC Press Release, December 11, 2014, "FCC INCREASES RURAL BROADBAND SPEEDS UNDER CONNECT AMERICA FUND"; *see also CAF Phase II Order* at ¶ 15.

[12] *See In the Matter of Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act, 2015 Broadband Progress Report and Notice of Inquiry on Immediate Action to Accelerate Deployment,* GN Docket No. 14-126, FCC 15-10, released February 4, 2015 (*"2015 FCC Broadband Progress Report"*) at ¶ 3.

[13] New applications and services have resulted in a demand for broadband speeds of 20 Mbps or higher. http://www.cio.ca.gov/broadband/pdf/CBTF_FINAL_Report.pdf , (accessed January 15, 2015), p. 12.

[14] "The Facts and Future of Broadband Competition," Speech of Chairman Tom Wheeler, Federal Communications Commission, 1776 Headquarters, Washington, D.C., Sept. 4, 2014, at 3.

[15] *In the Matter of Connect America Fund et al.*, *Report and Order*, WC Docket Nos. 10-90, 14-58 and 14-192, FCC 14-190, released December 18, 2014 ("*CAF Phase II Order*") at ¶ 16.

significant increases in Internet demand come from the fast-rising use of broadband applications, especially video and music/voice, which require much greater bandwidth than email text or normal web browsing."[16] Both wireless and wireline broadband networks will need to continue to evolve to meet these changing demands and the increased speed and capacity that customers will require.

2.2 Scarce Public Funds Should be Directed to Wireline Broadband

The Telecommunications Act of 1996 ("the Act") stated that universal service policy should change to support an evolving level of communications services. Even though broadband has not yet been identified as a supported service, broadband clearly represents such an evolution. Under the Act, rural and insular customers must have access to universal services that are reasonably comparable in quality and price to the services offered to customers in urban areas. Since high-quality broadband services can generally be delivered at a lower cost per customer in more densely populated areas, broadband in urban areas is normally more available than it is in rural areas. Speeds of 100 Mbps are commonly available to many urban customers at a reasonable cost.[17] At least a dozen U.S. cities currently have gigabit service[18] and many more gigabit deployments are planned over the next few years.[19] As broadband becomes the communication medium of choice for most Americans, the infrastructure necessary to bring broadband to all Americans must be planned for and built. Central to this endeavor is the United States' universal service public policy,[20] which helps fund broadband networks.

The current universal service policy challenge is to provide sufficient funding to induce providers to deploy comparable, high-quality broadband in rural areas with the Commission "encourag[ing] recipients of funding to deploy to the extent possible future proof infrastructure that will be capable of meeting evolving broadband performance obligations over the longer term."[21] Providers must have

[16] Robert J. Shapiro, "The Internet's Capacity to Handle Fast-Rising Demand for Bandwidth", http://www.usiia-net.org/pubs/Demand.pdf (accessed November, 14 2014), 9.

[17] For example, Verizon offers broadband FiOS packages with speeds up to 500 Mbps downstream and 100 Mbps upstream. (http://www.verizon.com/home/fios/#fios-experience as of November 14, 2014) Midcontinent Communications offers its Xstream Wideband service with up to 200 Mbps downstream and has recently announced Gigabit services in some of its markets. (http://www.midcocomm.com/) Comcast, Cox and Time Warner all offer 150 to 300 Mbps or higher downstream speeds in urban areas. (http://www.comcast.com/internet-service.html, http://www.cox.com/residential/internet.cox?sc_id=cr_z_red_z_highspeedinternet_vanity, and http://www.timewarnercable.com/en/internet/internet-service-plans.html as of November 14, 2014)

[18] Accessed November 14, 2014. http://highspeedgeek.com/america-gigabit-internet/. According to High Speed Geek, these cities are Kansas City, Mo; Chattanooga, TN; Lafayette, LA; East Lansing, MI; Bristol, VA; Morristown, TN; Burlington, VT; Springfield, VT; Tullahoma, TN; Minneapolis, MN; Cedar Falls, IA; and Seattle, WA. These cities do not include other communities that are "Gig-capable" through fiber installations to the premise.

[19] AT&T has announced that it has committed to providing or is exploring the possibility of providing GigaPower, its 1 Gbps broadband service, in 25 metro areas. (http://about.att.com/story/att_eyes_100_u_s_cities_and_municipalities_for_its_ultra_fast_fiber_network.html as of November 14, 2014.) Google is also exploring expansion of its 1 Gbps Google Fiber service in 34 cities in 9 metro areas. https://fiber.google.com/newcities/ as of January 16, 2015.

[20] *See, e.g.*, "*USF/ICC Transformation Order* at ¶¶ 1-3.

[21] *CAF Phase II Order* at ¶ 18.

sufficient revenues to make a business case for deploying and maintaining the infrastructure necessary to provide broadband to rural customers, who live in areas where there are so few customers that customer revenues alone would not induce a provider to make the initial infrastructure investment or maintain the infrastructure. Universal funding supplements customer revenues – which can only be obtained through rates that are "reasonably comparable" to those in urban areas – to make rural investment feasible. If universal funding dollars are scarce, then it is rational that any determination of substitute networks eligible for support should be based on an analysis of a comparable consumer experience. This paper provides such an analysis.

3 Specific Technical Metrics Define High-Quality Broadband

A network's physical and technical characteristics determine its performance, capabilities, and limitations. The following performance criteria can be used when evaluating broadband networks: speed, latency, capacity, reliability and scalability. Some network limitations are technical in nature and cannot be overcome, whereas other limitations are economic. While it may be possible to overcome the economic limitations by making additional investments in a network, in rural areas overcoming such economic obstacles may raise additional demand on scarce universal service dollars, thus requiring consideration of whether those investments can be made in networks that cannot readily be scaled to meet the customer's broadband demand, now or in the future.

3.1 High Speed

Broadband "speed" is the rate at which data can be delivered and is often measured in megabits per second ("Mbps") or gigabits per second ("Gbps"). Broadband speed can be thought of as how fast the data can flow through the broadband "pipe", which is a physical cable for wireline broadband or the air for wireless or satellite broadband. Cisco projects that globally, the average fixed broadband connection speed will increase from 16 Mbps in 2013 to 42 Mbps by 2018.[22] With regard to broadband speed, FCC Chairman Wheeler has stated, "Today, a majority of American homes have access to 100 Mbps. It is that kind of bandwidth that we should be pointing to as we move further into the 21st century. And while it's good that a majority of American homes have access to 100 Mbps, it is not acceptable that more than 40% do not."[23]

3.2 Low Latency

Latency refers to the delay that occurs from the time that a piece of data is sent to the time when it is received at the destination. Network latency is most commonly measured in milliseconds ("ms").

Many interactive broadband applications are adversely affected as latency increases. High latency can limit consumers' ability to use "real-time" applications, such as voice, video conferencing, Virtual Private Networking, remote learning, and telemedicine. With interactive two-way applications, round-trip latency is important since delays in delivering data can substantially degrade the quality of the application or make it unusable. New broadband investments must ensure sufficiently low latency to support voice-grade service and other real-time applications, which is why the FCC proposed to require a roundtrip latency of 100 ms or less for recipients of CAF support.[24]

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[22] http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html (accessed January 16, 2015).

[23] "The Facts and Future of Broadband Competition," Speech of Chairman Tom Wheeler, Federal Communications Commission, 1776 Headquarters, Washington, D.C., Sept. 4, 2014, p. 3.

[24] *See In the Matter of the Connect America Fund*, *Report and Order*, WC Docket No. 10-90, DA 13-2115, released October 31, 2013 (the "*PC Carrier Standards Order*") at ¶ 20.

3.3 High Capacity

Network capacity is a physical limitation on the quantity or volume of data that can be delivered to a broadband user during a given time period. Capacity is measured in megabytes ("MB") or more commonly, gigabytes ("GB") per month.

Similar to consumers' increased demand for broadband speed, consumers' demand for capacity continues to grow. Figure 3-1 shows the FCC's summary of customers' data consumption by technology based on September 2013 test data.[25] The data show that 20 to 25 percent of the customers served by coaxial and FTTP networks utilize more than 100 GB of capacity per month. Because data capacity is an important part of customers' broadband experience, the FCC is proposing a minimum capacity of 100 GB per month per customer, as a predicate for receiving federal CAF support.[26]

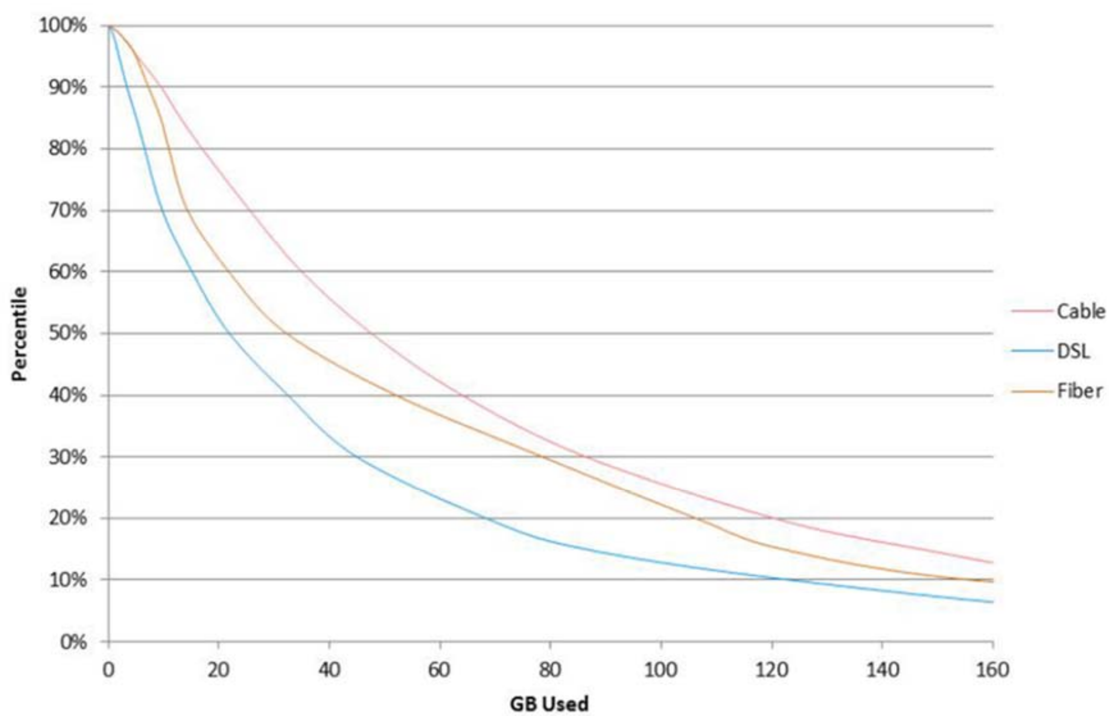

Figure 3-1: User Data Consumption by Technology per Month

Some networks have technical restrictions that limit customers' capacity. Satellite networks and most wireless networks are an example of this, because their customers share the network capacity. This sharing occurs in the "last mile" portion of the network which is referred to as the "access network," since it is where the customer "accesses" the provider's network. These networks may be designed to deliver data at reasonably high speeds, but for only short bursts of time. Dedicating network capacity to

[25]Accessed November 14, 2014. http://www.fcc.gov/reports/measuring-broadband-america-2014 , Chart 24, p. 51.
[26] *PC Carrier Standards Order* at ¶ 16.

one user means less capacity is available to the other users sharing the same access network. In networks where customers share the same broadband access network such as wireless and satellite networks, applications that demand continuous data delivery over long time periods (*e.g.,* video) can quickly exhaust the network's capacity. DSL and many types of Fiber to the Home ("FTTH") or Fiber to the Premises ("FTTP") networks[27] have cable (*i.e.*, the broadband access communications channel) dedicated to a single customer and therefore do not share their access networks.[28]

3.4 High Reliability

Reliability refers to a customer's ability to dependably use the network at different times and under various conditions. Customers are increasingly demanding a reliable broadband connection because they depend on their broadband connection for e-commerce, entertainment, education, telemedicine, and many other needs.[29]

Some broadband networks can be affected by environmental conditions, terrain, interference and the distance between the subscriber and the service provider's electronics.[30] Technologies that are affected by environmental conditions, weather or interference are generally less reliable, since these factors are beyond the network provider's control.[31]

3.5 Economical and Scalable

Nielsen's law, theorized by Jakob Nielsen in 1998, states that broadband demand for high-end users grows at a rate of 50% a year, as illustrated by Nielsen in Figure 3-2.[32] This theory has proven largely

[27] Today, there are two main competing FTTP technologies: Gigabit-capable Passive Optical Network (GPON) and Active Ethernet. Most GPON implementations use optical splitters to serve customers using a single fiber from the central office. GPON technology is defined by the International Telecommunications Union (ITU) standards and currently allows for speeds up to 2.4 Gbps downstream and 1.2 Gbps upstream. This bandwidth is normally shared by between 8 and 32 customers. Active Ethernet systems use a dedicated fiber between the central office and the customer, so the broadband consumption of one customer does not affect the amount of broadband available to other customers. In addition, Active Ethernet systems are symmetrical, meaning they provide equal downstream and upstream rates. Today, most Active Ethernet systems can provide up to 1 Gbps to each subscriber, with some providing up to 10 Gbps per customer.

[28] All broadband networks share capacity on the core network, the portion of the network between the provider and the Internet backbone.

[29] For example, broadband networks are increasingly used for access to emergency services. Many modern telemedicine applications, such as remote surgeries, could be life threatening if a network outage were to be experienced at the wrong time.

[30] These factors will be discussed at length later in this paper.

[31] Environmental factors include electromagnetic interference.

[32] Jakob Nielsen, "Nielsen's Law of Internet Bandwidth", http://www.nngroup.com/articles/law-of-bandwidth/ (accessed November 14, 2014).

correct over the past decade, and broadband speeds are expected to continue to rise at similar or greater rates.[33]

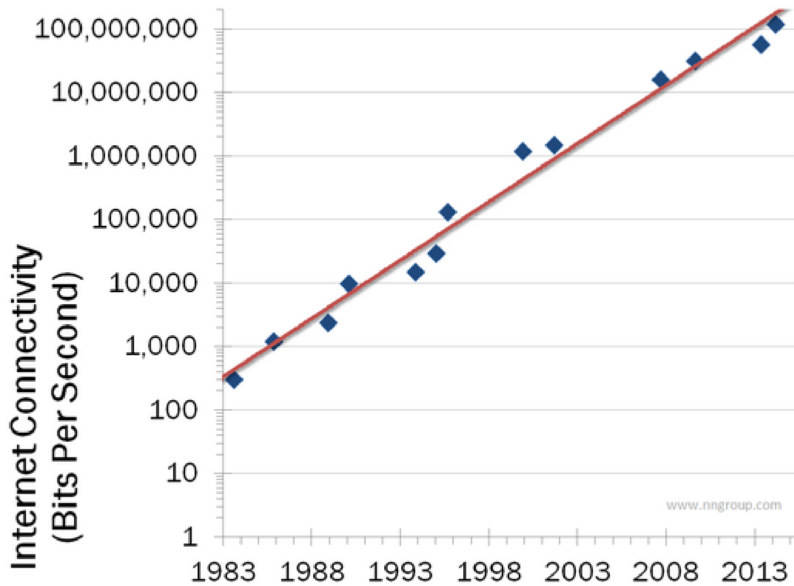

Figure 3-2: Nielsen's Law

An assessment of a broadband investment should consider not only existing broadband demands but also the anticipated broadband demands over the expected life of the facility. Consumers will likely soon demand, and broadband applications will require, minimum speeds of more than 100 Mbps and capacities much greater than 100 GB per month. If networks are not easily scalable to meet the increased customer demand, the networks may become obsolete before the end of their economic lives. It would be short-sighted and expensive if a broadband network required significant upgrades or had to be replaced altogether before the end of its economic life simply because it can no longer meet customers' broadband demands. To this end, the FCC has required CAF recipients to provide service with a latency of 100 ms or less, a minimum monthly capacity of 100 GB per month, and speeds of at least 10 Mbps. In addition, the FCC has made clear its expectation that, to the extent possible, network investments should be "future proof" with respect to increased speed capabilities.[34]

[33] Cisco projects that the average fixed broadband connection speed will increase from 13 Mbps in 2013 to 42 Mbps in 2018. http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html (accessed January 16, 2015).

[34] *CAF Phase II Order* at ¶ 15.

4 Wireless Networks Have Limited Broadband Capabilities

The broadband provided over wireless networks unquestionably plays an important role in the lives of consumers today. Many consumers rely on the broadband available on their mobile devices for access to social networks, news, small screen video and many other applications. Nevertheless, most consumers and policymakers view mobile broadband connections as being complementary, rather than a replacement for, wireline broadband connections. [35]

Another use of wireless technology is terrestrial fixed wireless, which some believe could be a lower cost alternative to wireline broadband.[36] Fixed and mobile wireless networks share many network elements; therefore they share many characteristics. Some characteristics of wireless networks limit their utility when used for general-purpose broadband delivery. The quantity and type of spectrum, proximity of customers to the provider's antenna, weather and geographical factors, and the number of network users all affect the wireless network's ability to deliver quality broadband. Each of these factors will be discussed in the following sections.

4.1 Limited Spectrum Constrains Broadband Speed and Capacity

The frequency and amount of spectrum[37] used by a wireless broadband provider affects a broadband network's maximum speed, capacity, reliability, and deployment costs. Spectrum is a limited resource and expensive for a wireless carrier to secure. Only a small portion of the available spectrum is available for commercial broadband communications, as depicted in Figure 4-1.

The limited amount of available spectrum significantly constrains the amount of broadband that can be provided, particularly when spectrum is used for the shared access portion of the wireless network. When additional spectrum is not available, a broadband provider must add towers to increase capacity, which increases deployment cost. Further, the available spectrum is scattered across various frequency bands, each with its unique propagation characteristics. Small providers typically only have 12 to 20 MHz of spectrum, while larger carriers may be able to afford 50 to 130 MHz of spectrum in some markets. Although 50 to 130 MHz may sound sizeable, it is currently inadequate for most urban areas and will be insufficient in rural areas as broadband demand continues to grow.

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[35] *See, e.g.*, "The Facts and Future of Broadband Competition," Speech of Chairman Tom Wheeler, Federal Communications Commission, 1776 Headquarters, Washington, D.C., Sept. 4, 2014, at 2 ("[T]oday it seems clear that mobile broadband is just not a full substitute for fixed broadband, especially given mobile pricing levels and limited data allowances.")

[36] Federal Communications Commission, Connecting America: The National Broadband Plan, released Mar. 16, 2010, (National Broadband Plan).

[37] Wireless technologies transmit communication signals on a radio frequency ("RF"). A range of radio frequencies are called spectrum.

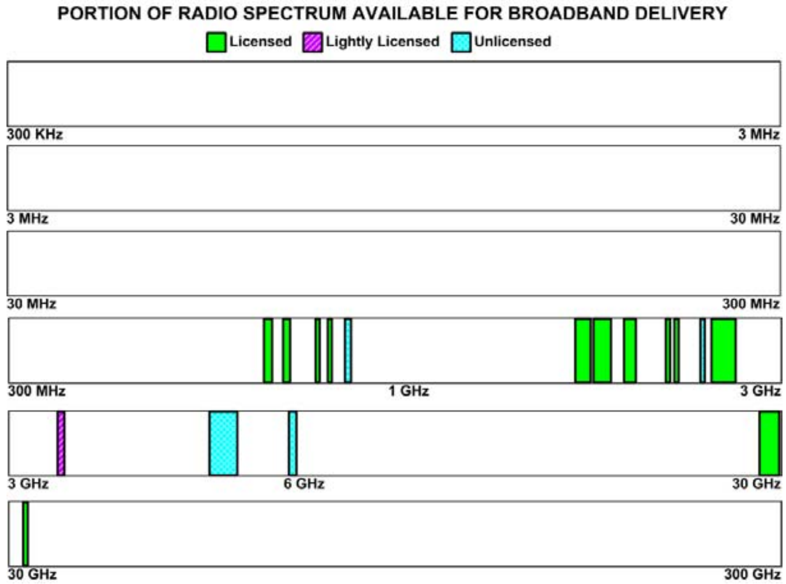

Figure 4-1: Portion of Radio Spectrum Available for Broadband Delivery

As part of its National Broadband Plan,[38] the FCC proposed that 500 MHz of spectrum be made available for broadband, 300 MHz of which was to be made available within 5 years.[39] Now five years after the National Broadband Plan, only 65 MHz spectrum has been made available[40] and no other auctions are planned until early 2016. The FCC's AWS-3 Auction has shown that spectrum is in very high demand[41] and nearly all currently available spectrum has been previously allocated to other uses. It has been Vantage Point Solution's ("VPS's") experience that concessions must often be made to existing spectrum holders and there is often significant expense associated with clearing spectrum for broadband uses. Uncertainties remain as to how much and when additional spectrum will be made available. One thing is clear, additional spectrum will be expensive if the AWS-3 auction is any indication.

Given that enough spectrum will likely not become available to meet the broadband demand, only "cell-splitting"[42] or the use of other spatial diversity techniques can be used to improve throughput capacity. Unfortunately, "cell-splitting" or other spatial diversity techniques are usually not economically viable in sparsely populated rural areas. Unlike fiber technologies, where capacity increases are less costly, every incremental increase in capacity of a wireless network will always be at a significant cost.[43]

[38] Federal Communications Commission, Connecting America: The National Broadband Plan, released Mar. 16, 2010, (National Broadband Plan).

[39] Id, p. 84.

[40] The 65 MHz spectrum was auctioned as part of the AWS-3 auction.

[41] The FCC's AWS-3 auction surpassed $40 billion for 1,614 licenses.

[42] Cell splitting refers to the use of smaller cells to reuse frequencies.

[43] Spatial diversity techniques are costly because of the increased processing power required and the multiple physical antennas necessary for both the base station and user equipment.

Spectral limitations have a significant impact on the broadband delivery capabilities of a wireless service, as shown in Table 4-1. The typical speeds shown are the average downstream speed capability. Lower speeds would be achieved at the cell edge.

Spectrum Name	Typical Contiguous Spectrum Amount (MHz)	Typical Speed Downstream Speed (Mbps)	Typical Distance Cell Edge (Miles)
700 MHz	2 x 6 (FDD)	8.5	20
850 MHz (Cellular)	2 x 10 (FDD)	17	17 ½
2 GHz (PCS and AWS)	2 x 15 (FDD)	26	8
2.5 GHz (BRS/EBS)	1 x 20 (TDD)	21	6 ½

Table 4-1: Typical Spectrum Capabilities

For example, assume a wireless provider holds a 700 MHz license with two 6 MHz channels, one for the upstream and one for the downstream. If that provider were able to achieve 2 bits per Hz on all 6 MHz,[44] the spectrum could deliver 12 Mbps. Even if this capacity were dedicated to a single customer – which it is not – the available speed and capacity are far less than what is available over most wireline broadband networks.[45] To provide a 100 Mbps symmetrical broadband service commonly offered by wireline providers, 1 GHz of spectrum would be required with today's Frequency Division Duplexing ("FDD")[46] equipment, as shown in Equation 4-1.

$$\left(\frac{100\ Mbps\ Downstream}{2\ bps\ per\ Hz} + \frac{100\ Mbps\ Upstream}{2\ bps\ per\ Hz}\right) \times 10 = 1\ GHz$$

Equation 4-1: Spectrum Required for 100 Mbps Symmetrical Service

This amount of spectrum is far greater than any carrier would be able to obtain. To provide a 1 Gbps symmetrical service would require the entire spectrum from 1 to 11 GHz — obviously an unlikely result. Further, given that broadband speeds have been increasing by approximately 50% per year, even if a wireless network were able to meet customers' broadband needs today; it is unlikely that the wireless network could meet customers' future broadband needs.

Only spatial diversity techniques,[47] which use multiple paths simultaneously on the same frequency, improve the *apparent* spectral efficiency of a given amount of spectrum. Unfortunately, many

[44] In practice, only 5 MHz of spectrum would be useable.

[45] Many wireline service providers offer speeds of 100 Mbps or more and several are offering 1 Gbps services. A 1 Gbps wireline service is more than 80 times faster than the 12 Mbps service available using 700 MHz spectrum.

[46] VPS assumed that separate frequencies were utilized for the upstream and downstream, a spectral efficiency of 2 bps per Hz and a 10:1 oversubscription ratio to create a high-probability of delivering 100 Mbps service.

[47] These techniques are called 5G.

techniques to increase broadband throughput also increase network complexity and cost. Plus, VPS estimates that any benefits will likely be realized only by customers in close proximity to the tower. Once the technology evolves, wireless providers could use spatial diversity techniques such as beam-forming, where isolated beams on the same frequency are directed toward specific users or expand the use of Multiple Input – Multiple Output (MIMO) techniques.[48] Today 2x2 MIMO techniques are common, but in the future 4X4 or 8X8 MIMO could be used.[49]

4.2 Distance from Antenna Reduces Broadband Speed

An important determinant of a broadband customer's connection speed is the proximity of the customer to the tower. The farther a customer is from a tower, the lower the signal strength and thus the lower the customer's connection speed. A customer located at the edge of the tower's range may experience more that 60% degradation in data rates relative to the average speed for customers closer to the tower.[50] As reflected in Figure 4-2, Motorola's analysis shows how a customer's broadband speed changes as the customer's distance from the provider's antenna increases.[51]

In rural areas, customers may live a long distance from the closest tower, which frequently are spaced 10 to 20 miles apart. At this distance, service may be extremely slow or non-existent. These "cell-edge" customers decrease the spectral efficiency and thus the throughput capability of the entire cell so the service of "closer-in" customers is affected by the presence of "cell-edge" customers.[52]

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[48] MIMO uses multiple antennas at both the user device and the base station to simultaneously send coded transmissions on the same frequency that are decoded by sophisticated digital signal processors. These signals can be multiple, reinforcing copies of the original user data stream to assist with NLOS customers; or, in strong signal areas, the signals can carry subsets of the user data that can be added together to improve throughput.

[49] At both the base station and end user site, 2x2 MIMO utilizes two antennas, 4x4 MIMO utilizes four antennas, and 8x8 MIMO utilizes eight antennas.

[50] The Broadband Availability Gap, OBI Technical Paper No. 1, Federal Communications Commission, April 2010, p. 66.

[51] Accessed December 08, 2014. http://www.motorolasolutions.com/web/Business/Solutions/Industry%20Solutions/Government/Public%20Service/_Documents/Static%20Files/Real%20World%20LTE%20Performance%20for%20Public%20Safety%20FINAL.pdf

[52] One might argue that a cell's coverage area be shrunk to only serve the "closer-in" customers that can avail themselves of higher modulation rates. However, this practice would raise the interference for all neighboring cells, which would lower the neighboring cells' throughput capacity. Thus, except where there are no neighboring systems, this practice would be self-defeating. Even if this practice were not self-defeating, in sparsely populated rural areas there are not enough customers to justify the construction of a large number of towers, which based on VPS's experience cost between $150,000 and $700,000 each.

Figure 4-2: Snapshot of Instantaneous User Throughput within a Typical 10MHz Sector[53]

4.3 Weather and Geography Limit Wireless Availability and Reliability

Wireless service can be degraded or eliminated altogether by obstacles[54] or weather conditions. Wireless RF signals used for broadband require a "line of sight" ("LOS") between the transmission tower and the customer. Mountains, hills, buildings, and trees interfere with the propagation of the wireless signal.[55] To some extent, LTE can provide non-line-of-sight service ("NLOS"), but at significantly reduced throughput compared to direct LOS. Terrain and obstacle challenges mean that some customers cannot receive a broadband signal, unless additional towers are constructed. Moreover, some operating frequencies are highly susceptible to attenuation due to rain, fog, or snow, which can also reduce broadband speeds and even cause network outages.

4.4 Increased Number of Users Reduces Wireless Broadband Speed

The "access" portion of a broadband network is the portion of the provider's network closest to the customer and is so named because it is the connection that the customer uses to "access" the provider's

[53] To widen a wireless coverage area without construction of another tower, several wireless antennas are frequently installed on the same tower. Each antenna serves a wireless sector.

[54] Common obstacles include buildings, hills and trees.

[55] Accessed December 08, 2014. http://www.motorolasolutions.com/web/Business/Solutions/Industry%20Solutions/Government/Public%20Service/_Documents/Static%20Files/Real%20World%20LTE%20Performance%20for%20Public%20Safety%20FINAL.pdf, p. 4.

network. For a wireless network, the access portion is the wireless link between the customer and the wireless tower.[56] Since the access portion of a wireless network is shared by many users, each user's network speed and available capacity declines as more users attempt to use the network.

For example, if a carrier controls 20 MHz of spectrum and provided service using 4G LTE (10 MHz used for upstream and 10 MHz used for downstream), the carrier could potentially deliver 15 to 20 Mbps to each customer on average, with some higher speed bursts.[57] Although these speeds would be barely adequate for a single user based on the FCC's current requirements, this available wireless capacity is shared by all customers serviced in the same sector.[58] If 100 customers were using the network at the same time, each customer would effectively receive between 150 kbps and 200 kbps on average – only a small fraction the FCC's definition of broadband. If only two of the 100 customers being served were to watch an HD video,[59] there would only be 6 Mbps of capacity available to the other 98 customers. If a third customer attempted to use a similar service, that customer would likely be blocked. Clearly, such degradation of service would be unacceptable to most customers.

A wireless network is a shared access network, and is often significantly over-subscribed.[60] Oversubscription works successfully when customers use the network for very short bursts of time. As consumers' Internet traffic patterns change to include more IP video,[61] it is more difficult for shared access networks to continue to meet customer demands. As IP video becomes more commonplace in remote learning, remote medical treatment, communication, social networking, and entertainment, individual users will be consuming larger portions of the access network for longer periods of time. Unless the oversubscription of the network is remedied, customers' network experience will be unsatisfactory.[62] Solving this problem on a wireless network comes at a significant cost, as will be shown later in Section 5.1 of this paper.

4.5 Frequency Band Impacts Broadband Capabilities

The spectrum's frequency also affects the number of towers required. The higher the frequency of the spectrum, the shorter its propagation distance and penetration ability will be. Shorter propagation distances require more towers to be constructed which causes the cost of a wireless broadband network

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[56] For a landline network, the cable connecting the customer to the central office or the head-end is the access portion.

[57] Today's predominant technology is Long Term Evolution ("LTE"), marketed as 4G LTE. This technology can achieve an average spectral efficiency of 1.5 to 2.0 bits per second of actual throughput per Hz of spectrum.

[58] A sector is a single access point radio.

[59] A typical High Definition (HD) video used for telemedicine, video conferencing, distance education, or entertainment, often requires 7 Mbps.

[60] The amount of "oversubscription" on the network refers to the ratio of all customers' subscribed bandwidth to the network's capable bandwidth.

[61] In 2013, 66% of all consumer Internet traffic was some form of IP video. By 2018, Cisco estimates that IP video will account for 79% of all Internet traffic.

[62] Oversubscription is the reason why a mobile wireless device may have good speeds late at night when few users are on the network, yet can be almost unusable in the afternoon when there are hundreds or thousands of people using their mobile devices.

to increase. Generally, spectrum up to 6 GHz is best for broadband delivery systems,[63] and spectrum below 1 GHz is optimal for rural areas where there are long distances between consumers and towers.

Since interference can seriously degrade performance or even cause a complete network outage, the FCC requires users to have a license to operate in most bands. There are three levels of licensing: unlicensed, lightly licensed and licensed.

- *Unlicensed Spectrum* - A number of unlicensed wireless technologies use 900 MHz, 2.4 GHz or 5 GHz spectra. Wireless Internet Service Providers ("WISPs") primarily utilize unlicensed or "lightly licensed" spectra.[64] In addition to utilization for broadband delivery, these unlicensed spectra must be shared with equipment being utilized for Wi-Fi, Bluetooth, agricultural GPS telemetry and control, cordless phones, garage door openers, baby monitors, microwave ovens, and many more applications.[65] Since operators in unlicensed spectra have no legal protection against interference – including from a competitor – interference can seriously degrade performance or even cause a complete network outage. Unlicensed wireless broadband is often used only as an adjunct service to fixed broadband.[66]
- *Lightly Licensed Spectrum* – "Lightly licensed" systems are available for the 3.65 GHz band. This spectrum must be shared with all service providers no matter which entity deployed its network first. The "lightly licensed" spectrum requirements only oblige users to register base stations and to coordinate with others.
- *Licensed Spectrum* – Mobile wireless carriers, as well as many fixed wireless carriers, rely on licensed spectrum in the 700 MHz, 850 MHz (Cellular), 2 GHz (PCS and AWS) and 2.5 GHz (BRS/EBS) licensed bands. By using licensed frequency bands, no other network may interfere with the wireless carrier's broadband signal.

Given unlicensed spectrum's increasing interference problems, providers utilizing unlicensed spectrum will continue to struggle to find wide, unencumbered, contiguous channels to satisfactorily meet customers' ever-increasing bandwidth demands. Because of the reliability, throughput and capacity concerns associated with unlicensed spectrum, VPS excluded these products from consideration in the test case to follow.

4.6 Wireless Capabilities are Reaching Theoretical Limits

As the number of users on the network increases and their usage grows at a rapid rate, wireless providers can address the bandwidth challenge in several ways: obtain more spectrum, use spectrum more efficiently, build more towers, or impose constraints on their customers. Given that spectrum is

63 Some WLAN technologies with peak theoretical speeds up to 1 Gbps are being discussed, but advancements in this area contemplate the use of unlicensed 60 GHz spectrum. The propagation of this frequency is limited to a few meters; thus, this spectrum is unsuitable for rural applications.

64 WISPA Ex Parte, March 10, 2014,WC Docket 10-90, p. 3.

65 http://www.ce.org/CorporateSite/media/gla/CEAUnlicensedSpectrumWhitePaper-FINAL-052814.pdf (accessed January 16, 2015)

66 Unlicensed wireless is commonly used for Wi-Fi service at the customer's premise.

both limited and expensive, providers must ensure that spectrum is used efficiently. The CTIA acknowledged the impact of scarce spectrum availability on wireless broadband services, stating "With the explosion in the amount of mobile data traffic, spectrum resources have not kept pace. Mobile broadband operators are thus constrained, necessitating aggressive and efficient management of limited radio resources."[67]

The spectral efficiency of a given technology determines the maximum throughput available per Hz of spectrum bandwidth. Many experts believe that 4G LTE performs at close to the theoretical limit of spectral efficiency. In 1948, mathematician Claude Shannon published "A Mathematical Theory of Communication", which has since become an industry standard. Shannon arrived at an equation that describes the relationship of the limiting factors of a communications channel's information transfer rate ability, shown in Equation 4-2.

$$C = B_{\omega} log_2 \left[1 + \frac{S}{N}\right]$$

$$B_{\omega} = Bandwidth\ in\ Hertz$$
$$C = channel\ Capacity\ in\ bits/second$$
$$S = Signal\ power$$
$$N = Noise\ power$$

Equation 4-2: Shannon's Capacity Equation

In general, for throughput Capacity (C) to increase, channel Bandwidth (B_{ω}) must increase and/or the Signal-to-Noise ratio (S/N) must increase.[68] The use of advanced modulation schemes allow future technologies to approach the theoretical limit of spectral efficiency predicted by Shannon's Law, 1.5 bps per Hz to 2.0 bps per Hz, as summarized by the FCC in Figure 4-3.[69]

According to Shannon's law, increases in signal power increases throughput capability. Increases in signal power[70] would be required in both base station and end user equipment, to maintain a balanced communication path. However, signal power increases may not be practical for end user equipment because of limits on device size, battery life, cost, etc. Even if signal power increases were practical, power increases tend to be self-defeating in point-to-multipoint wireless broadband systems, because such increases also increase the noise level in neighboring sectors, and thus, according to Shannon's Law, limit throughput capacity in those sectors. Cellular systems today operate at the optimal balance of signal power and acceptable noise as increases in one necessarily cause penalties in the other. It follows, then, that the only practical ways to increase throughput is to increase the amount of spectrum

[67] Accessed December 10, 2014. http://apps.fcc.gov/ecfs/document/view?id=60000871627, p. 2.
[68] For the Signal-to-Noise ratio to increase, Signal power (S) must increase and/or Noise (N) must decrease.
[69] The Broadband Availability Gap, OBI Technical Paper No. 1, Federal Communications Commission, April 2010, p. 65.
[70] FCC action is required for a provider to increase signal power.

or increase the number of towers. Either approach is expensive and difficult at best or impossible at worst.

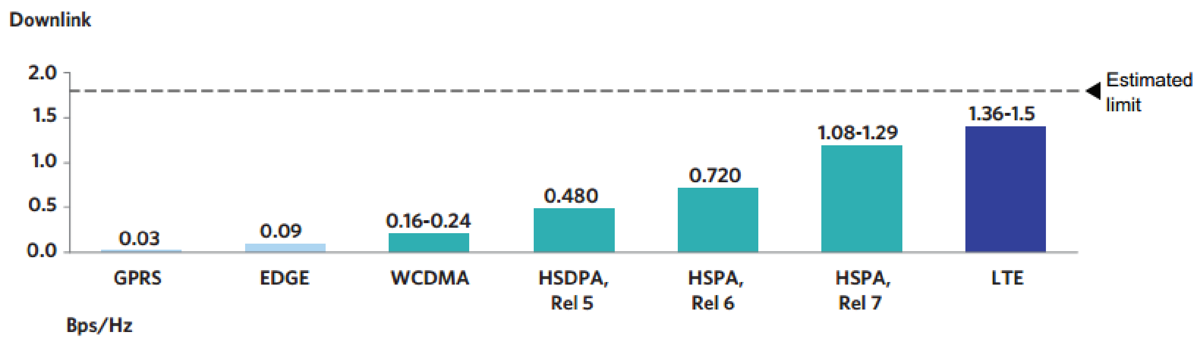

Figure 4-3: Average Spectral Efficiency

The consequence of this capacity limitation is reflected in the strict usage caps that wireless providers place on their customers. In contrast to wireline providers that have usage caps greater than 250 GB and often have unlimited usage plans,[71] wireless data packages include typical usage caps of between 10 and 30 GB per month,[72] with steeply higher rates for higher usage plans.

[71] Wireline Competition Bureau Provides Information Regarding Usage Allowance and pricing to Assist Applicant for Rural Broadband Experiments, WC Docket Nos. 10-90, 14-58.

[72] http://www.verizonwireless.com/landingpages/more-everything/ , http://www.att.com/att/planner/index.html#fbid=jAWDCjBSzXP

5 A Test Case to Compare Network Cost and Capability

This section compares the investment required to deploy a modern wireless network to that of a wireline network in a typical rural area. Not only does a provider want a network that can offer the most broadband for the least investment, but also one that minimizes operational expenses and can be cost effectively scaled to meet ever-increasing customer broadband demands. The cost of deploying and maintaining various broadband technologies is dependent on a number of factors, including:

- Customer Density and/or Number of Customers Served
- Type of Construction Corridors
- Land and Right of Way (ROW) Issues
- Labor and Fuel Costs
- Life Expectancy of the network
- Spectrum and Regulatory Costs
- Installation and Maintenance Costs

These factors impact wireline and wireless deployments differently and must be considered when determining which type of network provides the most economical broadband network. To compare the investment required for a "typical" service territory, VPS calculated the cost to build either a wireless or wireline network in the exchange of Chamberlain, South Dakota. A map of the Chamberlain service area is shown in Figure 5-1.[73] Based on VPS's experience in rural network design and deployment, Chamberlain represents an "average" or "typical" rural area with rolling hills, a small community, and sparsely populated outlying areas. From both a wireless and wireline perspective, Chamberlain is a moderately expensive area to serve.

[73] The Chamberlain exchange consists of 1,650 locations covering approximately 200 square miles in central South Dakota along the Missouri river.

Figure 5-1: Example Serving Area

5.1 Cost to Build a Wireless Network

The primary costs of terrestrial wireless networks are the towers, tower electronics, and backhaul. Rural towers have a much higher cost per customer than urban towers because there are fewer customers over which to spread the tower costs and backhaul facilities often require significant construction.[74] New towers are most costly where land or rights of ways ("ROWs") is expensive.[75] Land-use issues in general are more significant for wireless towers than for buried wireline facilities because of the visibility of wireless towers.

For the Chamberlain wireless design, VPS engineered a variety of scenarios in the following frequency bands and spectrum:

Frequency	Spectrum
700 MHz	2x5 MHz
850 MHz	2x10 MHz
PCS/AWS	2x15 MHz
BRS/EBS	1x20 MHz

[74] While microwave can be used for backhaul, recently fiber is displacing microwave because traffic demands can only be met using fiber facilities.

[75] ROW deployment times increase where permits must meet strict requirements for local environmental regulations, local zoning, protected plant or animal species, or areas of historical significance.

Each scenario developed a network with a high probability of delivering a 4 Mbps service while allowing the user to burst to 10 Mbps. LTE was chosen as the wireless technology because it is the most advanced technology available today and can be used for all of the chosen frequency bands, which includes the Time-Division Long-Term Evolution ("TD-LTE") variant for the BRS/EBS bands. With the subscriber density of Chamberlain and the service rate of 10 Mbps, any wireless network would be capacity constrained versus being range limited; therefore no cost reduction could be realized by utilizing sub-2 GHz bands which can propagate over longer distances. The analysis was based on the following assumptions:

- No spectrum costs were included. Spectrum prices vary widely from one market to another; thus, spectrum costs would be difficult to estimate for a specific geographic area. The exclusion of spectrum costs will give an economic advantage to the wireless network being examined here.
- All customers, both town and rural, would be served by the wireless broadband network as if no wireline network were available.[76]
- For the backhaul network, it was assumed that fiber would be installed from each tower to a central location within the exchange – the central office.
- Less than 6 percent of the estimated cost of the core network investment[77] was attributed to the Chamberlain design since it is assumed that there will be customers on other networks served by this core network.
- Due to the high speed and capacity requirements, towers were located close to each customer, thus enabling the use of lower-cost indoor residential LTE modems rather than more expensive outdoor modems.
- Due to the quantity of towers required by the design, each tower's serving area was small enough so that lower-cost towers could be used. Most towers were only sixty feet in height.
- A busy hour offered load ("BHOL")[78] of 444 kbps was assumed based on a 4 Mbps service and the FCC's prediction of what would be required by 2015.[79] Since the FCC standard is now 10 Mbps for CAF support, we also analyzed a system with a BHOL of 888 kbps.

The cost estimates for these examples are summarized in Table 5-1. For each example, a "Capacity Cost" was also calculated. VPS defines the Capacity Cost as the investment amount required to deliver 1 Mbps to the each customer.

[76] The analysis assumes that all 1,650 locations are being served.
[77] The overall project management fees are included in the Core Network investment.
[78] BHOL is the average demand for network capacity across all subscribers on the network during the busiest hour of the network. The Broadband Availability Gap, OBI Technical Paper No. 1, Federal Communications Commission, April 2010, p. 90.
[79] *Id.*, p.113.

	2x5 MHz Total Tower Sites: 29	2x10 MHz Total Tower Sites: 15	2x15 MHz Total Tower Sites: 10	1x20 MHz Total Tower Sites: 9
Radio Network Equipment	$4,181,000	$2,512,000	$1,918,000	$1,949,000
Core Network Equipment	$592,000	$342,000	$249,000	$229,000
Fiber Backhaul	$2,980,000	$2,636,000	$2,631,000	$2,423,000
Total Investment	**$7,753,000**	**$5,490,000**	**$4,798,000**	**$4,601,000**
Capacity Cost	**$470**	**$330**	**$290**	**$280**

Table 5-1: Example Wireless Initial Investment Costs (BHOL=444 kbps)

Since the minimum standard for CAF support is now 10/1 Mbps rather than 4/1 Mbps, a BHOL of 444 kbps is no longer adequate.[80] Therefore, VPS calculated the cost assuming a BHOL of 888 kbps, as summarized in Table 5-2.

	2x5 MHz Total Tower Sites: 58	2x10 MHz Total Tower Sites: 29	2x15 MHz Total Tower Sites: 19	1x20 MHz Total Tower Sites: 18
Radio Network Equipment	$7,638,000	$4,181,000	$2,971,000	$2,985,000
Core Network Equipment	$1,111,000	$592,000	$407,000	$384,000
Fiber Backhaul	$3,007,000	$2,980,000	$2,506,000	$2,408,000
Total Investment	**$11,756,000**	**$7,753,000**	**$5,884,000**	**$5,777,000**
Capacity Cost	**$710**	**$470**	**$360**	**$350**

Table 5-2: Example Wireless Initial Investment Costs (BHOL=888 kbps)

A comparison of the costs shows that significant additional investment is required as broadband demand increases.

5.2 Cost to Build a Wireline Network

There are three common technologies used by wireline companies today: Digital Subscriber Line ("DSL"), Data over Cable Service Interface Specification ("DOCSIS") over Coaxial Cable and Fiber-To-The-Premises ("FTTP"). These technologies are described as follows.

- DSL overlays a broadband signal on twisted pair copper cables, which is the physical facility traditionally deployed for "plain old telephone service," also known as "POTS." With DSL, broadband speeds are dependent on the customer's distance from the node, which can be located in a remote terminal or central office. Depending upon the gauge and quality of the cable, modern DSL technologies can achieve 10 Mbps when the customer is located less than 10,000 feet from the node.

[80] The FCC has now concluded that "advanced telecommunications capability" requires access to actual download speeds of at least 25 Mbps and actual upload speeds of 3 Mbps. *See 2015 FCC Broadband Progress Report* at ¶ 3.

- Coaxial cable can be used to provide broadband service at speeds in excess of 100 Mbps.[81] Similar to wireless broadband, DOCSIS technology shares capacity among many network users, so speeds will decrease as customers are added to the network. Because of the expense of the network architecture, DOCSIS is commonly only used in densely-populated areas.
- Fiber optic cable is the transmission medium for FTTP, which can provide each customer up to 1 Gbps of broadband. Much higher speeds will soon be available. Most FTTP networks are designed to serve customers more than twelve miles from the electronics, but technology exists to serve customers more than 20 miles from the electronics.

Fiber has been acknowledged as the best technology to construct modern broadband networks or to upgrade existing networks because it is immune to electromagnetic interference, provides the most reliable services, minimizes operational expenses, and is economically scalable to achieve higher broadband speeds.[82] Plus, fiber optics has the ability to deliver greater bandwidth over a much larger distance[83] and at a lower cost than other technologies.

In addition to the fiber cable, a FTTP network requires electronics at the customer premises and at the node. The cost of electronics per location serviced is relatively constant, while the fiber cable investment is quite variable and usually represents the majority of the cost. VPS's experience is that some of the more significant cost drivers for wireline deployments include:

- <u>Lower Customer Density</u> – In rural areas, there are few customers to spread the infrastructure costs which results in a high cost per customer.
- <u>Difficult Construction Corridors</u> – Terrain difficulties include obstacles such as rocks, lava flows, lakes, rivers, forested areas, and railroad crossings. The type and quantity of existing underground utilities also significantly influence construction costs since extra effort is required to circumvent the utilities.
- <u>Land and Right of Way Issues</u> – Cable construction becomes more difficult and costly where land or ROW is expensive.
- <u>Labor and Fuel Costs</u> – Cable construction is labor intensive and relies on the use and transportation of large equipment. Typically, 60 to 80 percent of the construction costs are labor related.

Table 5-3 shows the estimated FTTP initial investment to build an active Ethernet network capable of 1 Gbps, including the fiber construction, electronics, miscellaneous materials and overheads.

[81] Using the DOCSIS 3.0 or 3.1 standard.

[82] Once the fiber infrastructure is in place, broadband speed can be increased by a factor of 100 or more by upgrading the electronics, which, while requiring some additional investment, represents a proportionately small portion of the overall investment.

[83] The bandwidth delivered does not decrease as the cable length increases.

	Cost
Outside Plant	$6,900,000
Electronics	$1,560,000
Total Investment	**$8,460,000**
Capacity Cost	**$ 5**

Table 5-3: Example FTTP Initial Investment Cost

5.3 Wireline Network's Performance Surpasses that of the Wireless Network

Depending upon terrain, desired broadband speeds and other factors, it is not uncommon for the initial capital expenditure for a wireless broadband network to be less than the initial capital expenditure for a FTTP network. In this example, however, the initial cost of the wireless LTE network can be more or less than the wireline FTTP network depending upon the assumptions. Importantly, the performance of the two networks is not comparable. The wireless network was designed to have a high probability of delivering 4 Mbps and allow customers to occasionally burst to 10 Mbps.[84] Each customer on the FTTP network will receive 1 Gbps service no matter how many customers are using the network because it is not oversubscribed between the customer and the central office. When comparing the Capacity Cost, the FTTP network costs approximately $5 compared to between $280 and $710 for the wireless network. When comparing wireless and FTTP investments, it is important to consider the following:

- Spectrum costs were excluded from the example and could contribute significantly to the overall capital investment for wireless deployments.
- The majority of the FTTP investment is in cable facilities, whereas the majority of the wireless network investment is in electronics. The economic life of cable facilities is typically 30 years or longer, while electronics often last between 5 and 10 years. To appropriately compare the two networks from a financial standpoint, the different economic lives must be equalized, which will lessen any perceived cost savings for a wireless network.
- The FTTP network can be scaled to provide faster speeds and greater capacity much more economically than the wireless network. If users were to demand more than 1 Gbps service in the future, only the FTTP electronics would need to be replaced. Since the cost of electronics is proportionately lower in cost when compared to the initial deployment cost of fiber, the FTTP network can be upgraded cost effectively.

Both scenarios assumed that no existing facilities were considered in the design. The cost of a wireless network could possibly be reduced by using existing structures, but the decrease in investment would likely be small, considering the number of towers required to meet the speed and capacity requirements.

[84] Since the wireless network is oversubscribed, customers will likely experience speeds slower than 4 Mbps during busy hours. If all customers were using the network at once, each would only achieve 444 kbps, not 10 Mbps.

6 Wireline Technologies Are Best Suited to Meet Broadband Demands.

Engineering analyses confirm that wireline technologies are capable of providing the best broadband services in terms of speed, latency, capacity and reliability. Wireline technologies are capable of speeds many times faster than the preeminent wireless technologies. Plus, wireline technologies are plagued by neither latency issues nor the scarce spectrum resources that limit speed and capacity in wireless networks. The FCC has recognized that fiber is the only last-mile technology capable of meeting long-term broadband needs.[85] As indicated above, FCC Chairman Wheeler also recognized the superiority of fiber in meeting broadband needs: "In the end, at this moment, only fiber gives the local cable company a competitive run for its money. Once fiber is in place, its beauty is that throughput increases are largely a matter of upgrading the electronics at both ends, something that costs much less than laying new connections."[86]

Both wireless and wireline broadband services play important roles in many customers' lives and one will never displace the other.[87] Today's customers expect an assortment of applications in a variety of locations. Mobile wireless broadband services are required to meet customers' mobile needs, while wireline broadband services are required to provide high-quality broadband for the rich multimedia experience customers expect in their homes and businesses.

[85] The Broadband Availability Gap, OBI Technical Paper No. 1, Federal Communications Commission, April 2010, p. 76.

[86] "The Facts and Future of Broadband Competition," Speech of Chairman Tom Wheeler, Federal Communications Commission, 1776 Headquarters, Washington, D.C., Sept. 4, 2014

[87] Not only are wireline and wireless services complementary in the lives of their customers, but they are also complementary in the sense that wireless service depends on the speed and quality of wireline connections. In order for this to occur, wireless towers require high capacity connections, typically using Ethernet delivered over a landline carrier's fiber network.

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