Analysis of Satellite-Based Telecommunications and Broadband Services

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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]

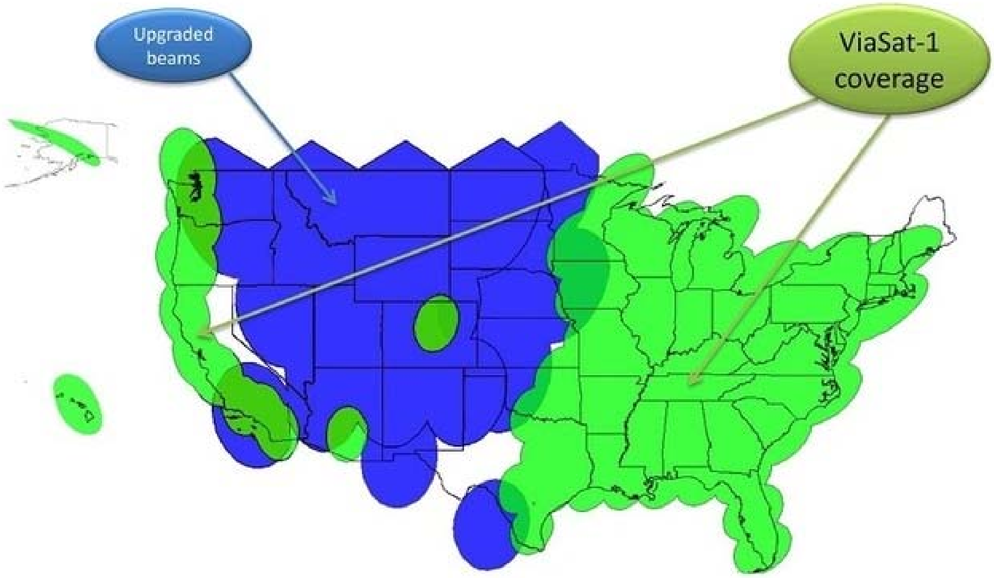

Figure 2-2: ViaSat Exede Coverage

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.

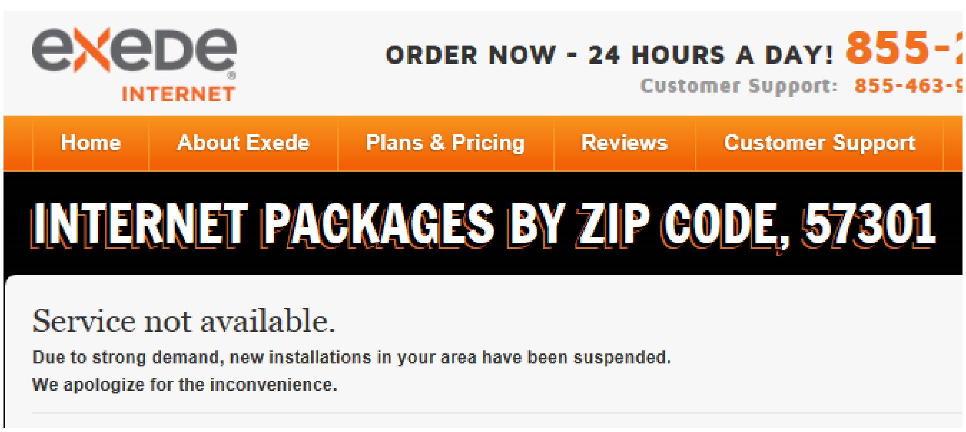

Figure 2-3: Exede New Installations Suspension Notice [https://order.exede.com]

[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

[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

[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.

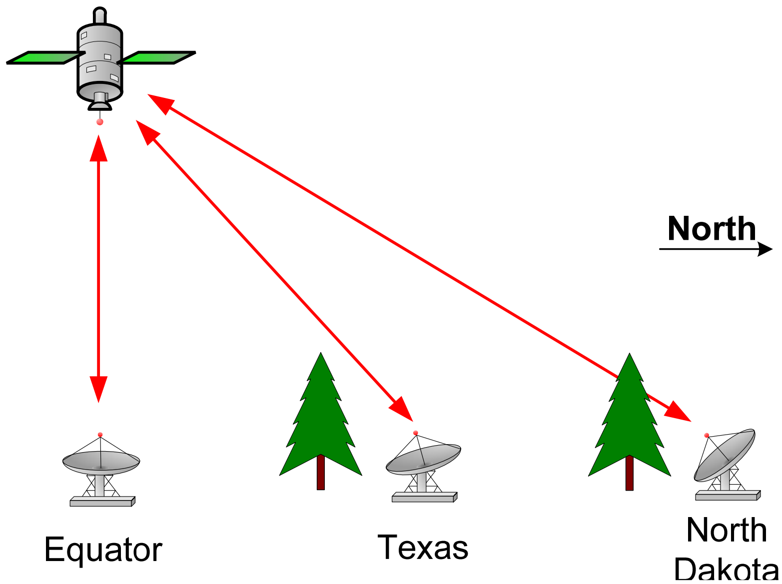

Figure 4-2: Satellite Dish Elevation

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]

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[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]

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[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.

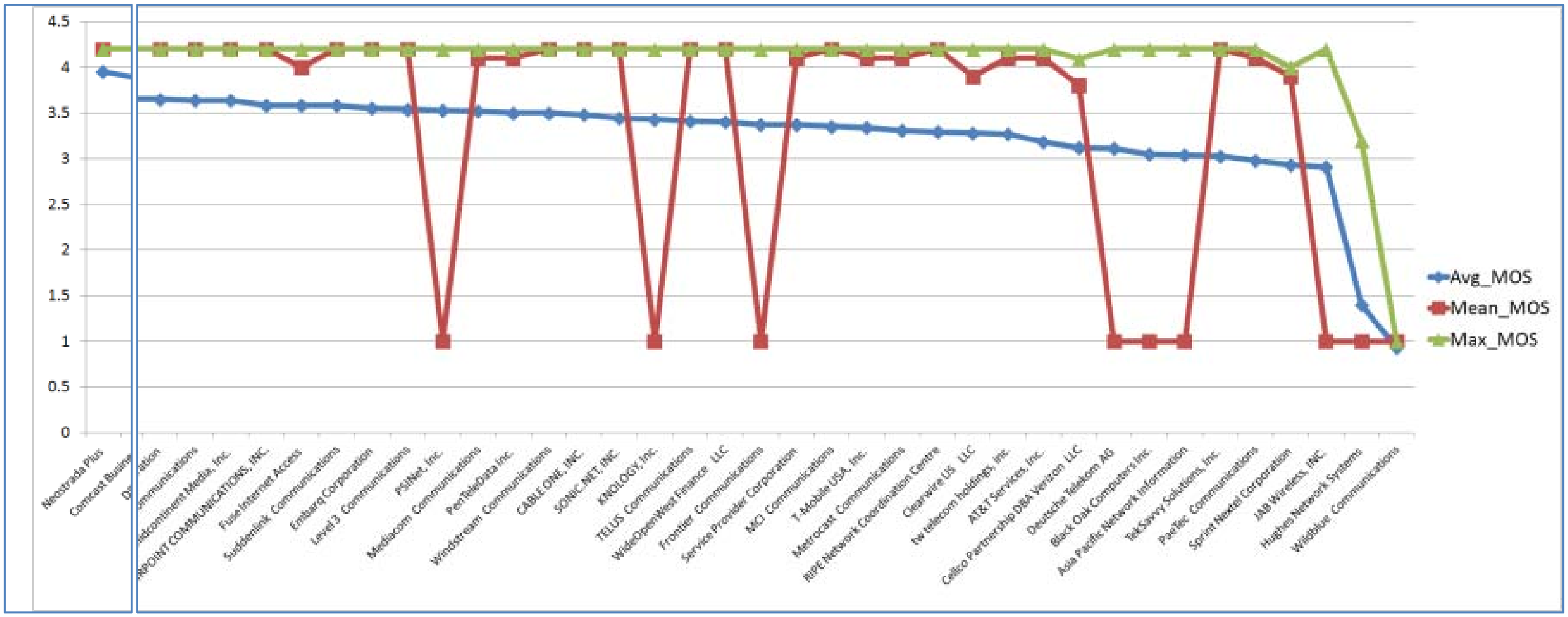

Figure 4-5: MOS Scores for Various Service Providers[43]

[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]

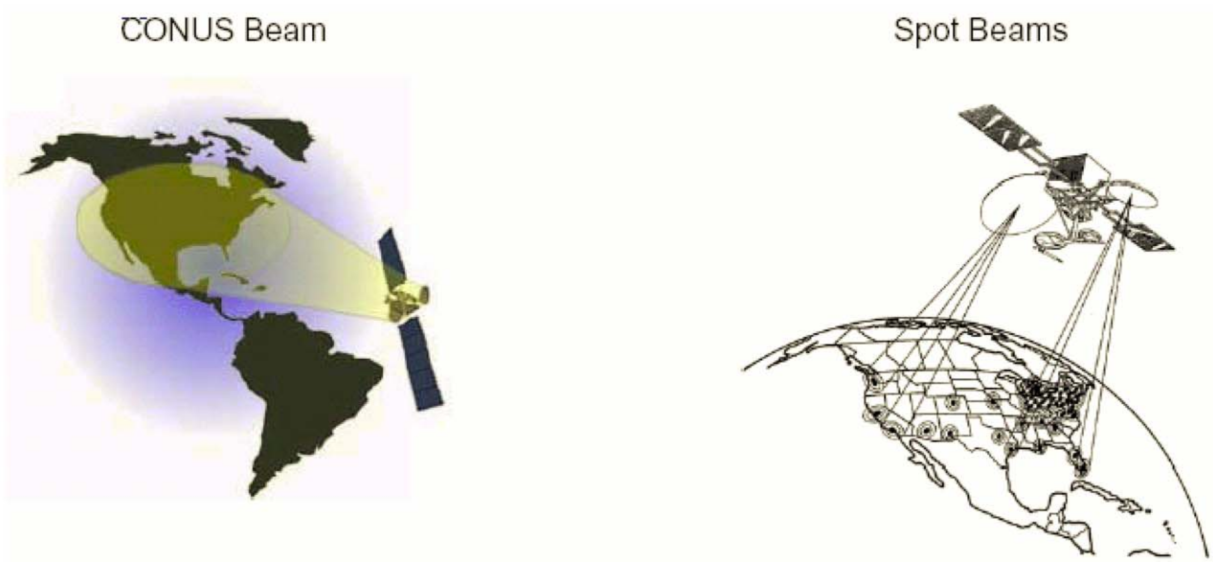

Figure 4-6: Spot Beam

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.

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[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.

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[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.

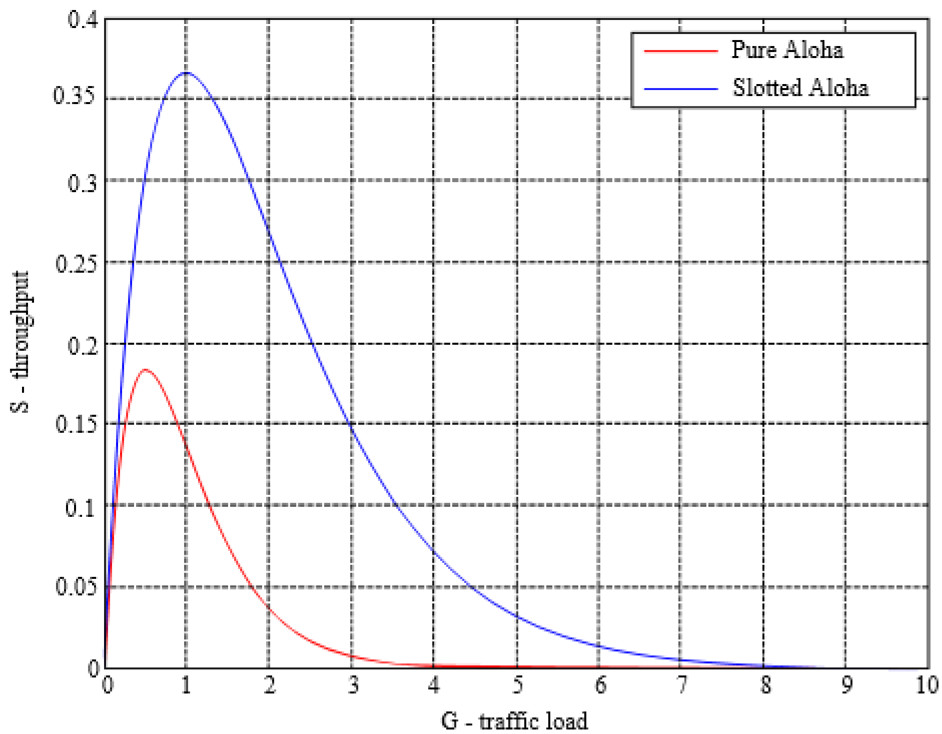

Figure 4-7: ALOHA Protocol Capacity versus Traffic Load[59]

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

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[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

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