2022

Is Digital Subscriber Line (DSL) still a

broadband technology?

Prepared for the South Carolina Office of Regulatory Staff by
DOUG DAWSON

This paper reaches the conclusion, for a wide variety of reasons, that DSL technology delivered over a single pair of copper wires should not be considered in future broadband expansion plans as a viable technology.

Introduction

The purpose of this discussion paper is to explore whether investments in Digital Subscriber Line (DSL) technology should be considered in South Carolina's future broadband expansion plans. The future of DSL technology is a relevant topic in South Carolina, because as of June 30, 2021, the state reported that 355,550 households are still using broadband provided by DSL technology[1].

This paper reaches the conclusion, for a wide variety of reasons, that DSL technology delivered over a single pair of copper wires should not be considered in future broadband expansion plans as a viable technology. While there is some DSL delivered using two bonded pairs of copper that can still achieve speeds faster than the Federal Communications Commission (FCC) definition of broadband of 25/3 Mbps, it is rarely available in rural areas and, further, it is the opinion of this author that the FCC speed definition is obsolete.

[1] Based on FCC Form 477 subscription information that was reported to the SC Broadband Office as of June 30, 2021.

Why is Broadband Usage Growing?

There are two reasons that the average household broadband usage continues to grow.[2] Homes are doing more things on the Internet and homes are using more bandwidth for the things they have always done. Not surprisingly, most homes are doing both.

There is no better example than video conferencing. The pandemic forced millions of people home and kept family and friends apart, and seemingly overnight everybody in the country knows what a Zoom meeting is. Since a Zoom connection requires dedicating both an upstream and a downstream broadband connection, the collective amount of bandwidth used for video meetings in the last year was astronomical. While these applications have been around a few years, the usage in 2019 for video meetings is a tiny fraction of the usage we've seen in 2020 and 2021.

Today, files are automatically saved and stored live online and work product can be loaded into several other share drive programs to collaborate with others on different projects. This is all a new use of bandwidth that didn't exist just a few years ago.

The biggest driver of household broadband usage is video (although machine-to-machine traffic for things like automatic file backups is catching up). As recently as 2017 almost all online video was transmitted in high definition or lower resolution. But the big platforms like Amazon and Netflix began streaming everything in 4K video, and the amount of broadband used to watch shows and movies skyrocketed.

In 2015, the FCC defined broadband as 25/3 Mbps by engaging in a thought experience to estimate the average broadband usage for a family of four.[3] The FCC discussed less than a dozen uses of broadband and those few different tasks captured how most of us used the Internet in 2015. Today there is no longer a

Recommended video bitrates for HDR uploads		
Type	Video Bitrate, Standard Frame Rate (24, 25, 30)	Video Bitrate, High Frame rate (48, 50, 60)
2160p (4K)	44-56 Mbps	66-85 Mbps
1440p (2K)	20 Mbps	30 Mbps
1080p	10 Mbps	15 Mbps
720p	6.5 Mbps	9.5 Mbps
480p	Not supported	Not supported
360p	Not supported	Not supported

[2] "It is important to track the changing mix of devices and connections and growth in multidevice ownership as it affects traffic patterns. Video devices, in particular, can have a multiplier effect on traffic. An Internet-enabled HD television that draws couple - three hours of content per day from the Internet would generate as much Internet traffic as an entire household today, on an average. Video effect of the devices on traffic is more pronounced because of the introduction of Ultra-High-Definition (UHD), or 4K, video streaming. This technology has such an effect because the bit rate for 4K video at about 15 to 18 Mbps is more than double the HD video bit rate and nine times more than Standard-Definition (SD) video bit rate. We estimate that by 2023, two-thirds (66 percent) of the installed flat-panel TV sets will be UHD, up from 33 percent in 2018" See Cisco Annual Internet Report (2018-2023) White Paper , https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html (Last accessed Aug. 23, 2021), cited in Federal Communication Commission's Eleventh Measuring Broadband America Fixed Broadband Report (rel. Dec. 31, 2021).

[3] See Inquiry Concerning the Deployment of Advanced Telecommunications Capability to AllAmericans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate SuchDeployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act; GN Docket 14-126, 2015 Broadband Progress Report and NOI on Immediate Action to Accelerate Deployment (rel. Feb. 4, 2015).https://www.fcc.gov/sites/default/files/household_broadband_guide.pdf. FCC Household Broadband Guide reflects a family of four utilizing four devices as needing medium service or 25 Mbps (rel. Feb. 5, 2020)

typical broadband household because there are hundreds of ways to use broadband. Simple differences like having gamers in a home or having somebody working fulltime from home can distinguish one neighbor from another in terms of a broadband usage profile.

Perhaps the best way to illustrate the continuous growth in broadband usage is to identify the bandwidth needed for everyday household broadband functions.

Video

There is a high variability in video bandwidth because every online service uses different compression ratios. For example, Netflix states that standard streaming requires 3 Mbps download, high definition requires 5 Mbps, and 4K/Ultra HD needs 25 Mbps. Hulu uses different compression technology and recommends 3 Mbps for standard streaming, 8 Mbps for live streams like sports, and 16 Mbps for 4K content. And none of these speeds are fixed. It takes more bandwidth to carry an action-packed scene than a quiet scene where the background stays constant. Content providers also downgrade quality to fit the broadband speed they encounter at a user. One of the first things that a customer upgrading to fiber usually notices is the improved video. A household using DSL has never seen a 4K video, because Netflix and others tamp the signal to a lower quality to fit the available broadband.[4]

Zoom

There is a high variability in Zoom video bandwidth because Zoom modifies the stream to fit a user's video capability.[5] The lowest resolution uses a 600/600 kbps stream (up and down). 720p video quality uses 1.2/1.2 Mbps, which 1080p quality uses 3.8/3 Mbps. Those bandwidths are for a call between only two parties. The download bandwidth used increases when connected to multiple users. Extra upload bandwidth is needed to share files or share videos.

Video Gaming

The amount of bandwidth needed for gaming varies widely by the platform and the game, with needs for download data streams between 1 Mbps and 30 Mbps. Starting in 2019, the major game platforms have started to migrate gaming to the cloud. This means gamers no longer buy CDs or download huge game files. Currently, other major platforms like Facebook, Amazon, and Microsoft have joined the migration to the cloud to allow gaming to be played on any device and not on proprietary game consoles.[6]

Home Security Services

The most common 4K cameras operate at 1080p, and the chart below shows that translates into 10 – 16 Mbps. Over the last few years, millions of homes installed video cameras that can be set to record in the cloud. The low-resolution cameras we've used over the last decade have required 1-3 Mbps upload bursts to the cloud per camera. The following table shows the upload bandwidth needed for various 4K cameras (the speed is a function of the number of pixels in the image and the number of video frames transmitter per second.[7]

[4] On auto setting, Netflix adjusts the streaming speed to match the actual internet speed. https://help.netflix.com/en/node/87

[5] https://assets.zoom.us/docs/user-guides/User%20Guide%20-%20Optimizing%20Performance%20in%20Low%20Bandwidth%20Environments.pdf

[6] https://www.nytimes.com/2021/07/01/technology/cloud-gaming-latest-wave.html

[7] https://www.google.com/search?q=recommended+video+bitrates+for+HDR+uploads&rlz=1C1GCEA_enUS995US995&oq=recommended+video+bitrates+for+HDR+uploads&aqs=chrome..69i57j0i10j0i390l4.8341j1j15&sourceid=chrome&ie=UTF-8

Transportation

Another new upload broadband use is smart cars. One manufacturer strongly suggests connecting the car to the cloud, although it's not mandatory. The connection can be made through a monthly subscription with a cellular carrier specifically for the vehicle, or by connecting the car to the home Wi-Fi network. When connected to Wi-Fi, it uploads statistics about driving performance and diagnostics every time it comes into range of the home Wi-Fi. The connection also allows the manufacturer to download software upgrades to the car. [8]

Every one of the broadband uses described requires more bandwidth than only a few years ago. New broadband usages will present another magnitude larger than today.

- YouTube is already accepting 8K videos that require a little over 50 Mbps download stream. There are already 8K TVs in stores, and those come with the capability of 100 Mbps downstream to do picture-in-picture.
- There are already developers working on content for online HD virtual reality, and there are estimates that the technology could require download streams as fast as 167 Mbps.

[8] https://www.subaru.com/engineering/starlink/connectivity.html

Digital Subscriber Line (DSL)

DSL is a transmission technology that delivers bandwidth over twisted-pair copper telephone wires. Like many of the communications innovations of the last century, the concept for DSL came out of Bellcore, the offshoot of Bell Labs. The invention of DSL is credited to Joseph Lechleider, but the technology was polished and commercialized by Stanford Professor John Cioffi (known as the "Father of DSL").[9]

Traditional telephone service transmits signals using radio frequencies inside of a pair of copper wires. Traditional telephone voice service operates using frequencies between 1 and 3,400 hertz – which can also be expressed as 3.4 kilohertz (kHz). Copper wire operating in that frequency range can carry up to 56 Kbps (kilobits per second) of data, which was the maximum speed of dial-up broadband over telephone wires.

DSL pushes past the 3.4 kHz frequency limit and transmits data at higher frequencies. Similar to any technology using radio frequencies, the higher the frequency and the wider the range of the frequencies being used, the greater the amount of data packets that can be transmitted – and the greater the transmission speed that can be achieved. The first widely sold generation of commercial DSL had a download transmission data rate of 1 Mbps (1,000 kilobits) – which carried 18 times more data than a traditional telephone dial-up connection.

The term DSL represents a wide range of different technologies. The first patents for ADSL, the first widely deployed variety of DSL, were filed in 1988 - thirty-four years ago.[10]

[9] https://en.wikipedia.org/wiki/Digital_subscriber_line

[10] Id.

The most deployed types of DSL can be categorized into five families of technology:

ISDL

This early form of DSL emulated Integrated Services Digital Network (ISDN) service and could transmit a 144 kbps ISDN signal to 18,000 feet, which could be extended with a repeater. ISDN was a data transmission technology and a predecessor to DSL, introduced in 1988.

SDSL (Symmetric DSL)

This early DSL supported a symmetrical data stream up to 1.544 Mbps.

HDSL (High Bit-Rate DSL)

This largely replaced SDSL and transmitted a symmetrical data stream at speeds between 1.544 Mbps and 2.048 Mbps. This technology provided a cheaper way to transmit a traditional T1 and is still used for this purpose.

ADSL (Asymmetric DSL)

This is a family of DSL that introduced asymmetrical data speeds, with most of the speed assigned to the download path. First-generation ADSL uses frequencies on the copper from 25.875 kHz to 138 kHz for upload and between 138 kHz and 1,104 kHz (1.104 MHz) for download. ADSL2+ extended the frequency range further to 2.2 MHz.

VDSL (Very-high-data-rate DSL)

VDSL technology reaches into higher frequencies and uses spectrum between 25 kHz and 17.665 MHz. The trade-off for using higher frequencies is a shortening of the distance the data can be carried before it degrades.

G.fast

DSL technology has continued to evolve. G.fast uses frequencies on copper up to 212 MHz and delivers speeds up to 1 Gbps, but for very short distances, such as inside of a building. This paper does not examine G.fast technology.

This discussion paper will concentrate on the most deployed DSL in the consumer market, which is ADSL, ADSL2+, VDSL, and VDSL2+.

DSL is a standards-based technology, which theoretically means that equipment should be interchangeable between vendors – but during the heyday of the DSL industry, this was rarely the case. There were dozens of DSL vendors manufacturing DSL equipment and each had some different twist or feature to differentiate its brand in the market. This makes it impossible to precisely talk about the capabilities of any specific type of DSL because the speed and performance of DSL differed by the vendor and also by the specific feature set as vendors constantly introduced new tweaks and features into existing DSL products.

As an example, the following Table 1 shows some of the commercially common types of DSL just in the ADSL technology family[11]:

Table 1

Variety of ADSL	Download	Upload	Introduced
ADSL	8.0 Mbps	1.0 Mbps	1998
ADSL (G,dmt)	8.0 Mbps	1.3 Mbps	1999-2007
ADSL over POTS	12.0 Mbps	1.3 Mbps	2001
ADSL over ISDN	12.0 Mbps	1.8 Mbps	2005
ADSL2	12.0 Mbps	1.3 Mbps	2002 - 2007
Splitterless ADSL	1.5 Mbps	0.5 Mbps	2002 - 2007
ADSL2+	24.0 Mbps	1.4 Mbps	2003 - 2005
ADSL2+M	24.0 Mbps	3.3 Mbps	2008

[11] https://en.wikipedia.org/wiki/Asymmetric_digital_subscriber_line

The Typical DSL Network

DSL networks have a simple configuration compared to other broadband technologies like cable company Hybrid Fiber Coaxial (HFC) networks or fiber-to-the-premise networks. The diagram below in Figure 1 demonstrates the simplicity of the network.

Description of basic DSL Network Elements

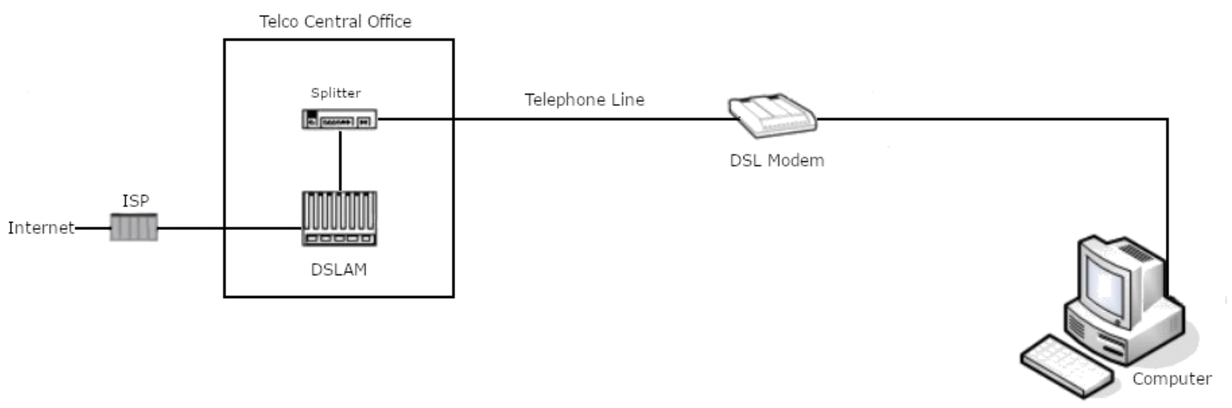
DSLAM

The Digital Subscriber Link Access Multiplexer (DSLAM) is the core device that establishes the two-way individual broadband signal going to each twisted pair of copper. The DSLAM communicates with customers using a modem, and there is a separate modem inside the DSLAM for each pair of copper wires.

The multiplexer function refers to the way that the DSLAM aggregates the traffic to and from customers. On traffic coming from the open Internet (at the left of the diagram), the DSLAM demodulates and separates the internet traffic aimed at specific customers and routes the traffic to the appropriate copper path to each customer. For traffic coming from the customer to go to the Internet, the DSLAM accepts the traffic from each customer and aggregates everything into one data path to the Internet.

The diagram refers to a DSL splitter. This is the device that allows routing of Internet traffic to specific copper pairs. In the early versions of DSL, this was a separate device but has largely been integrated into the DSLAM in newer technology.

Figure 1



When DSL was first deployed, the DSLAMs were located almost exclusively in telephone company central offices. Because of the distance limitation of the DSL signal, telephone companies began to deploy DSLAMs in the field closer to customers. This could mean placing a DSLAM anywhere in the network, such as at the entrance to a subdivision, in the basement of a giant apartment building, or even in a rural area in a hut to serve nearby farms. Early DSLAMs needed to be placed in cooled facilities, but over time the vendors developed 'hardened' DSLAMs that can be placed in non-air-conditioned huts in the field.

Twisted Copper Pair Wire

DSL must be transmitted to and from customers using a twisted pair of telephone wires. Twisted pair technology was introduced by Alexander Graham Bell, who demonstrated that two intertwined wires cancel out interference from the signal traveling through a single wire.

When DSL was first deployed, it required a 'dry loop', meaning that early DSL did not coexist well with a telephone signal. A dry loop carries no telephone dial tone and is also not connected to the DC power system that provides continuous power to customer devices in a telephone network. (This power from the copper pair is why a telephone used to continue to operate even when a home was without power). Vendors developed the technology to enable carrying both telephone and DSL broadband, and a line carrying both included a band-pass filter at the customer end that separated out any unneeded frequency from entering and interfering with the customer's DSL signal.

A DSL signal cannot handle one of the routine electronic elements in telephone voice networks. The range of frequencies that are used to carry human voice tends to get distorted as the signal is carried through copper in an analog telephone network. Telephone networks use loading coals on the outdoor copper lines to rebalance the transmission signal. The distance between loading coils is largely based upon the thickness of the copper wires and can be from one to three miles apart. The loading coils eliminate the higher frequencies in a DSL transmission, so telephone lines must be de-loaded or shuttled around the loading coils.[12] This might mean physically bypassing a load coil or replacing existing load coils with ones that still work for voice traffic but that pass higher frequencies.

The majority of commercial DSL uses a single pair of copper wires. However, it's possible to bond multiple pairs of copper wires together to obtain a stronger DSL signal.

While most DSL is provided by the telephone companies that own the copper lines, there is also a regulatory requirement in the U.S. for telephone companies to offer copper lines to competitors. This requirement was established as one of the primary features of the Telecommunications Act of 1996. The Act enabled a competitor to lease telephone company copper wires and connect its own technology to the wires. This regulatory practice is described as selling unbundled copper loops and is still being used today by competitors.

[12] https://isemag.com/2016/12/load-coils/

Factors that Affect DSL Performance & Reliability

The following are some of the major factors that affect DSL networks:

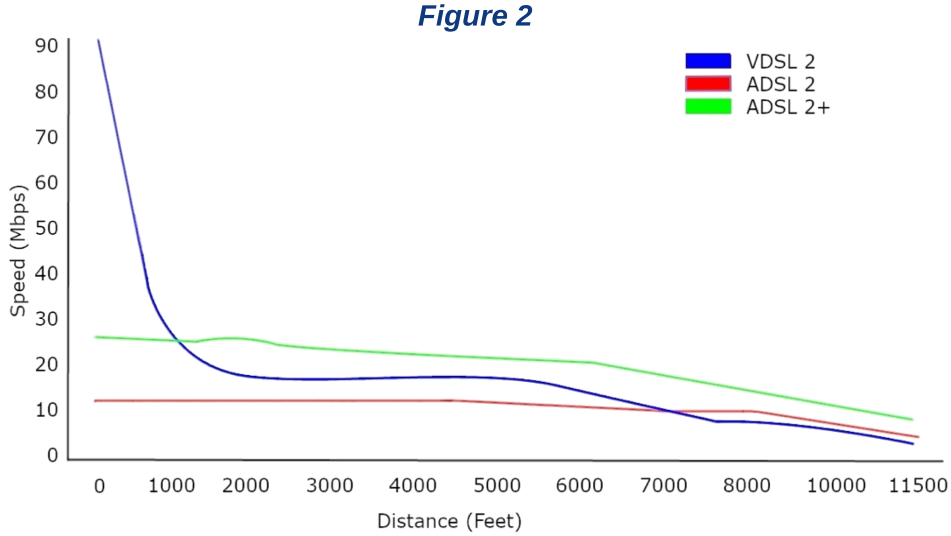
Factor #1: Distance

The most widely understood characteristic of DSL is that the amount of bandwidth that can be delivered decreases with distance from the DSLAM transmitter. A customer located one mile from a DSLAM will get a faster broadband connection than a customer located three miles away.

The signal strength decreases from a phenomenon referred to as attenuation. Attenuation occurs when a transmitted signal interacts with the transmission medium. Every transmission medium has attenuation, and there is signal loss when sending signals through telephone copper, coaxial copper, fiber, and even wirelessly through the air. A transmitted DSL signal gets weakened as the transmission bounces against the sheath surrounding the copper or interacts with small irregularities in the wire.

Each variety of DSL has a different pattern of attenuation losses. The following graph in Figure 2 shows the attenuation losses for the three most used types of DSL. Figure 2 shows that VDSL2 massively outperforms the other kinds of DSL for distances under 1,300 feet. At very short distances, a VDSL2 signal can deliver nearly 100 Mbps in speed. This capability has little practical use because there are typically not many homes within only 1,000 feet of a DSLAM. Theoretically, an ISP could use VDSL2 to create a 50 Mbps broadband product on a single copper pair by putting a DSLAM every 2,000 feet so that all customers are within 1,000 feet of the DSLAM.

Figure 2



The DSL variety with the best market-practical field characteristics is ADSL2+.[13] This technology can deliver DSL speeds of 20 Mbps or more download for distances up to 6,000 feet on good copper, with speeds still at 10 Mbps download at 10,000 feet. Figure 2 demonstrates that speeds decline quickly for all three varieties of DSL when distances exceed 10,000 feet.

It is important to note that the distances being discussed are the feet of copper wiring between the DSLAM and a customer.

[13] http://www.differencebetween.net/technology/difference-between-adsl-and-adsl2/

Factor #2: Condition of the Copper Wiring

The distances shown in the chart above represent the distances that can be delivered through good copper. Copper wiring degrades as it ages.

As the outer sheaths degrade, the wiring becomes noticeably corroded. The sheaths around copper wires expand and contract with temperature differences and get brittle and crack over time. Cables sway in the wind and stretch and crack the fiber and the sheath. Water leaks into cables and freezes in the cold of winter. Water also corrodes any exposed copper at splice points. There is extra attenuation created at every copper splice point that is added after the initial construction – the copper suffers a little from each repair after storm damage. Copper wires also erode very slowly just from the continuous passage of electricity - molecules of copper separate from the crystalline-like structure of a freshly extruded copper wire.

The accumulation of small damages and slow degradation is the primary reason that attenuation increases over time. Old copper wiring has more attenuation than new copper wiring, and DSL electronics cannot achieve the designed speeds on old copper wiring.

Factor #3: Size of the Copper Wire

Copper wires are manufactured at different thicknesses, and the thicker the copper wire, the stronger the DSL signal. The size of copper wire is defined by the American Wire Gauge standard. The smaller the gauge number, the thicker the copper. The most used sizes of copper wires on poles are 22-gauge (0.253 inches) and 24-gauge (0.0201 inches), although there are some deployments of older wires as large as 19-gauge and as small as 26-gauge. That may not seem like a big difference, but a 22-gauge copper is 26% larger in diameter than 24-gauge wire – which translates into more attenuation and poorer throughput through the smaller wire.

Factor #4: Crosstalk

The early generations of DSL suffered from significant crosstalk, which means there was interference between adjacent copper lines carrying DSL, particularly if there was a lot of DSL into a given neighborhood. This was particularly a problem with VDSL that uses higher frequencies. In neighborhoods with a lot of DSL customers, the crosstalk reduced data throughput by as much as 30%.

Over time, the vendors found electronics solutions that reduced the crosstalk. The solutions to crosstalk were eventually referred to collectively as “vectoring.” The easiest analogy for understanding vectoring is that the DSL signal ‘tightened’ so that fewer stray signals escape to interfere with nearby wires. Vectoring became so effective that it eventually almost eliminated crosstalk. But it’s still a concern because there are still some older varieties of DSL in use that don’t eliminate all the crosstalk.

Factor #5: Older Technologies Still in Use

One of the most common reasons for slow DSL is that some older DSL technologies are still in use. The large telephone companies installed DSL in some neighborhoods in the early 2000s that is still in use today. Most smaller telephone companies upgraded DSL over time. They may have originally installed a version of ADSL with a top speed of 6 Mbps, but over time upgraded to a mix of ADSL2+ and VDSL2 to deliver faster speeds. There is still plenty of the older generations of technology in use.

There is a second problem caused by the prevalence of older technologies. It gets harder every year for telephone companies to keep older DSL systems operating. DSL is a standards-based technology, meaning that DSL technology supplied by different vendors is supposed to be compatible and interchangeable. However, in the heyday of the DSL industry, every vendor was constantly introducing new features, and so there are dozens of slightly different versions of DSL even from the same vendor.

Telecommunications manufacturers typically stop supporting specific versions of any technology after about seven years. When a manufacturer stops supporting a specific variety of DSL, the vendor will stockpile some spares – but when those have been sold, no more are manufactured. This means that telephone companies that still maintain older varieties of DSL either must rely on spares purchased earlier, or shop on the gray market of used equipment such as on eBay.

Factor #6: DSL Loop Extenders

Figure 2 demonstrates that it is difficult to deliver DSL faster than 10 Mbps after 10,000 feet of good copper wiring, and the DSL signal is non-existent at approximately 18,000 feet.[14] That means that the outer reach of DSL served from a centralized DSLAM is only about 3 miles of good copper wiring.

The telecommunications industry solution to extend DSL farther into rural areas is to use DSL loop extenders. DSL loop extenders are field mounted along DSL routes and copper pairs that carry the DSL signal routed through the devices. Loop extenders come in two varieties: 1) An Amplifier that boosts the signal strength of the DSL signal and 2) A Regenerator to demodulate the DSL (like is normally done at a customer location with a DSL modem) and then remodulate the signal.

The downside to DSL loop extenders is a loss of speed. For example, the typical loop extender might have a maximum output of 4/1 Mbps – far slower than the original DSL signal. The use of DSL loop extenders enables customers located ten miles from a town to obtain DSL. However, the customer may experience slow speed DSL service.

Loop extender performance is affected by many of the issues described earlier. For example, loop extenders perform better on larger copper wires – but rural copper wires tend to be of the smallest gauges.

Factor #7: Backhaul

"Backhaul" refers to the overall amount of bandwidth made available to any neighborhood broadband technology. In the case of DSL, the backhaul refers to the amount of bandwidth that is supplied to a DSLAM.

Most DSLAMs are installed in telephone company central offices, fed by a fiber broadband connection, and operate with as much bandwidth as the DSLAM needs for maximum performance. However, the bandwidth deployed to remote DSLAMs may be a different story. For example, a DSLAM sitting in front of small subdivision may use a few T1s for backhaul. A DSLAM fed by four T1s would have a maximum amount of bandwidth of 6 Mbps.

---

[14] https://www.ccexpert.us/iscw/dsl-limitations.html

Factor #8: Inside the Customer Premise

There are several factors at the customer premise that can negatively impact DSL speeds.

Copper Drops

Degraded aerial copper wire drops contribute to the decline in DSL speeds to customers. An aerial copper wire drop is the wire that goes from a pole to a customer premise. Drops are smaller copper wire cables that contain only a few pairs of copper. Drops are more susceptible to degradation than the larger cables on poles. Drops are susceptible to movement of the wind and bump against trees or other obstructions. Drops can sag and water can accumulate inside the copper drop sheath.

Indoor Copper Wiring

Indoor copper wiring inside premises may degrade the DSL signal. For example, the wires might be of smaller gauge. Indoor wires may be damaged during installation if they are stapled to studs inside the wall. Wires might not be properly grounded and may pick up interference.

Wi-Fi

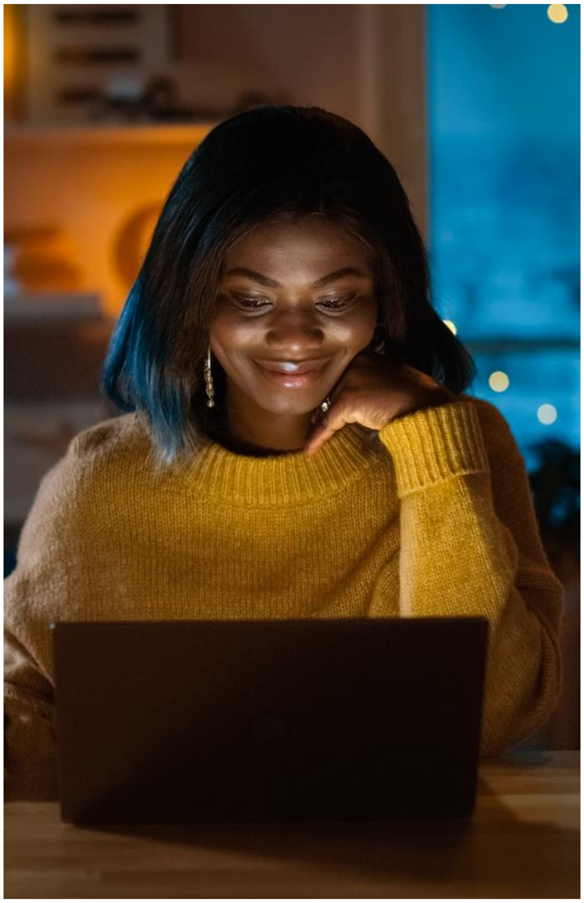
Most broadband customers today use Wi-Fi wireless technology to deliver broadband from the modem to devices. There are other factors that can degrade a Wi-Fi signal. For example, homeowners may use an outdated Wi-Fi router that does not have enough capacity to distribute the bandwidth that is delivered to the home. Homeowners may try to beam Wi-Fi through thick walls in older buildings or try to serve large areas from a single Wi-Fi router.

Factor #9: Oversubscription

DSL is a shared technology meaning that all the customers served from a single DSLAM share the total amount of bandwidth supplied to the DSLAM. Many of the problems experienced with DSL occur when aggregate neighborhood customer demand exceeds the bandwidth available at the DSLAM. Oversubscription refers to a situation where an ISP promises more bandwidth to customers than what is available.

The easiest way to understand oversubscription is with an example. Consider a DSLAM that serves 400 customers where the telephone company has promised to be able to deliver 20 Mbps download DSL. It requires eight gigabits of broadband to provide the full download bandwidth if all 400 customers try to use all the capacity at the same time. However, the telephone company supplies this DSLAM with one gigabit of bandwidth. In this example, the telephone company sold eight times more bandwidth than can actually be delivered – which means an “oversubscription” ratio of eight to one.

Oversubscription may be perceived as the ISP not acting in good faith by selling more bandwidth than



can be delivered. However, ISPs use oversubscription because they understand customers bandwidth usage patterns and habits. It's likely, in this example, that customers may almost always be able to use the expected 20 Mbps of bandwidth.

At any given time, many homes in a neighborhood are not using broadband. Even when broadband is being used, the usage levels are below 20 Mbps. For example, a home that is streaming a single Netflix show uses a few Mbps. The ISP relies upon the normal behavior of its customers, in aggregate, to know that, for most of the time, customers can use the bandwidth purchased.

However, even before the pandemic, DSL networks were grossly oversubscribed, meaning that the network got busier at peak times than the overall neighborhood bandwidth limit. When a neighborhood network gets too busy, every customer receives degraded broadband. There is a huge amount of documentation over the last decade about the poor performance of DSL.[15] For example, many states explored DSL performance through investigatory dockets and solicited comments from the public and from interested parties like the Communications Workers of America, which represents many union technicians that maintain DSL.[16]

The pandemic overloaded DSL networks that already struggled with lagging bandwidth. During the pandemic, people working from home and students with online schooling tried to make day-long connections to office and home servers. They also participated in Zoom and other online meetings which require a customer to use a fixed amount of both upload and download bandwidth. The available bandwidth in most DSL networks was completely consumed by those working from home. Once a network is full, other homes can't make connections. The result is that DSL networks are fatally oversubscribed, meaning they are unusable at popular times of the day.[17]

The allocation of bandwidth at the DSLAM is not the only place in the network that can be oversubscribed. Any other place inside the ISP network where customer data is aggregated and combined may face the same oversubscription issue. A common term used by DSL experts is "chokepoints." A chokepoint describes places in a network where bandwidth becomes constrained. There is a minimum of three chokepoints in every ISP network, and there can be many more. [18]In a DSL network, the bandwidth can be "choked" at the DSLAM, the primary network routers that direct traffic to and from the Internet, and on the backhaul path.

---

[15]https://www.technicallywizardry.com/how-to-speed-up-a-dsl-modem-router/#:~:text=Unfortunately%2C%20many%20DSL%20modem%20router,down%20and%202%20Mbps%20up.

[16] There have been dockets exploring DSL performance in many states. Some of the more recent such dockets include Case No. 17-00186-UT in New Mexico, Docket 2018-00319 in Maine, Docket No. IR 19-023 in New Hampshire, Docket 18-3231-PET in Vermont, and Case 16-C-0122 in New York.

[17] https://www.ctcnet.us/wp-content/uploads/2014/02/CTC-ConnectivityPerformanceFactorsBrief0213141.pdf

https://www.traficom.fi/en/communications/broadband-and-telephone/factors-affecting-speed-and-quality-internet-connection

[18] https://circleid.com/posts/20201215-understanding-broadband-oversubscription/

Factor #10: Upload Bandwidth Limitations

The factor that was most prevalent during the pandemic is the slow upload link. Almost every variety of DSL limits the upload path to a few Mbps. An upload speed of 1 Mbps or less will not easily connect or stay connected to work and school servers or to video services like Zoom. [19]

Factor #11: Gradual Loss of Institutional Knowledge

One factor that is rarely discussed but which affects DSL performance is a loss of institutional knowledge. The heyday of DSL was between 2000 and 2010. Many telephone companies no longer have these technicians and the people that understood DSL are not available. [20]

Factor #12: Availability to Subsequent Homeowner

Since DSL has been obsoleted by several large ISPs, most are unaware that existing DSL service may not be available to the subsequent homeowner. DSL service is available to the existing owner; however, once disconnected during a real estate transaction, the new owner may not be able to provision service.

Factor #13: Bonded Copper Wires

Basic DSL operates through two copper wires to a customer premise (referred to in the industry as a twisted wire pair). Most of the issues listed above can reduce the speeds that can be delivered over DSL. But there is one technology that improves DSL speeds.

It is possible to bond more than one pair of copper wires together to obtain faster broadband. Most telephone companies offer some bonded DSL service and the most common configuration uses four copper wires to double the bandwidth. It is possible to bond even more copper pairs together, and there are a handful of Competitive Local Exchange Carriers (CLECs) who use multiple copper pairs to create 100 Mbps download connections to business customers.

There are several factors that limit the use of bonded DSL. The first limitation is that only newer versions of DSL allow bonding technology. The second limitation is the availability of copper pairs to a given customer. There must be two available pairs of copper wire available at a customer site to use bonding technology. Because customers have elected to not have traditional landline telephone service in the last decade, there are usually spare copper pairs throughout the network. The third limitation is distance. Most telephone companies deploy bonded DSL within a set distance radius from the DSLAM, such as 6,000 feet. The benefits of bonding two DSL circuits together diminishes as the speeds reduce over distance.

[19] https://www.cnet.com/tech/services-and-software/broadband-use-surged-more-than-30-during-pandemic-industry-group-says/

[20] https://arstechnica.com/tech-policy/2020/10/life-in-atts-slow-lane-millions-left-without-fiber-as-company-kills-dsl/

The Definition of Broadband

The discussion paper reaches the conclusion, for a wide variety of reasons, that DSL technology delivered over a single pair of copper wires should not be considered in future broadband expansion plans as a viable technology. The definition of broadband is important to reaching this conclusion.

FCC Definition of Broadband

In 2015, the FCC defined broadband to be a data transmission of at least 25/3 Mbps (that's 25 Mbps download and 3 Mbps upload). Prior to 2015, the definition of broadband was 4/1 Mbps, set in 2010. The original definition of broadband established by the FCC was in 1996, with broadband defined as 200/200 kbps.[21]

The FCC is required to define broadband to meet a legal requirement established by Congress in Section 706 of the FCC governing rules created by the Telecommunications Act of 1996. Section 706 requires that the FCC "shall determine whether advanced telecommunications capability is being deployed to all Americans in a reasonable and timely fashion. If the Commission's determination is negative, it shall take immediate action to accelerate deployment of such capability by removing barriers to infrastructure investment and by promoting competition in the telecommunications market."[22]

The FCC listed the broadband functions that a typical family of four was likely to engage in and determined that a 25/3 Mbps broadband connection was fast enough to satisfy the broadband needs of a typical family.

The FCC asked again in 2018 and 2020 if 25/3 Mbps is still an adequate definition of broadband but took no action to change the 25/3 Mbps definition. Numerous parties filed comments to indicate the definition of broadband should be increased.

[21] See 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; GN Docket 14-126, 2015 Broadband Progress Report and NOI on Immediate Action to Accelerate Deployment (rel. Feb. 4, 2015).

[22] Section 706 of the Telecommunications Act of 1996.

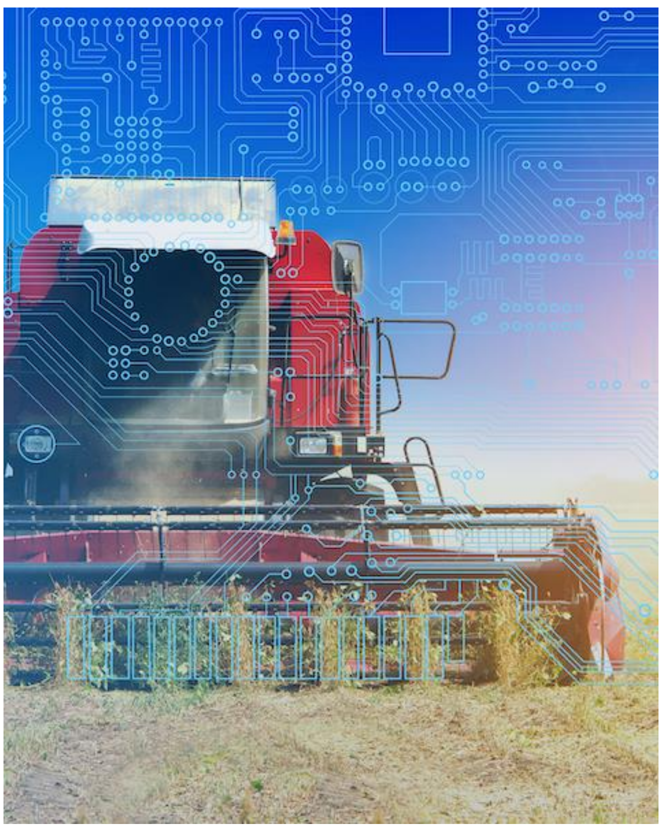
FCC Measures Broadband Speeds

Section 706 also requires the FCC to issue a report each year to Congress concerning the state of broadband.[23] In these reports, the FCC compiles data about the number of homes and businesses in the country that subscribe to broadband as well as the speeds and availability of broadband. In each annual report, the FCC offers an opinion on the state of broadband in the country.

To compile annual reports, the FCC collects data from ISPs about deployed broadband that is sold to customers across the U.S. The FCC collects ISP data using a process called the Form 477 process. The FCC collects the following data from every landline broadband ISP in the country:

Subscription

ISPs report broadband service level options and customer counts (both residential and commercial) by Census tract.



Deployment

For each Census block, the ISPs report the type of technology in use as well as the maximum advertised download and upload speeds that are available to customers. Census blocks are finite geographic areas defined by the U.S. Census bureau that typically cover between 60 and 120 homes. In a city, a Census block might be a city block, and in a rural area, it might cover a relatively large portion of a county.

After the FCC gathers the data from ISPs, the FCC publishes the data as a database. The database has become known in the industry as the "FCC Broadband Maps." [24]

FCC to Revise Maps

In January 2020, the FCC voted to revise the data gathering and mapping system, and Congress provided the funding for this to happen at the end of 2020.

The biggest change in the broadband data collection process is that ISPs must provide street addresses or draw polygons around areas where customers either have service or where the ISP is willing to provide service within ten days of a customer request.[25]

[23] The FCC report to Congress for 2020 can be found at https://docs.fcc.gov/public/attachments/FCC-20-50A1.pdf and https://docs.fcc.gov/public/attachments/FCC-20-50A2.pdf.

[24] https://broadbandmap.fcc.gov/#/

[25] https://www.fcc.gov/BroadbandData/filers

This means service areas will be specifically identified, and that whole Census blocks won't be shown as being served due to one or two customers. The changes by the FCC may address two inherent problems. First, the changes will create a clear border to demonstrate where cable company coverage stops in towns. Today, reporting by Census block often shows cable coverage extending far into the rural areas surrounding towns. Second, the polygons may reduce the number of companies that claim coverage where they are unable to provide service.

The revised mapping rules provide for a two-tier challenge process – a challenge by governments or Tribes and a challenge by consumers. The government challenge is complex in that any government that wants to challenge the FCC databases must draw their own versions of the polygons in an area they are challenging.

A consumer may challenge that a broadband product is available at their home, and if they are proven to be correct, the ISP must redraw the polygon to exclude them.

Most recently, the FCC moved forward and selected a vendor, Cost Quest, to provide broadband location data. The new maps will rely on the Broadband Serviceable Location Fabric.[26]

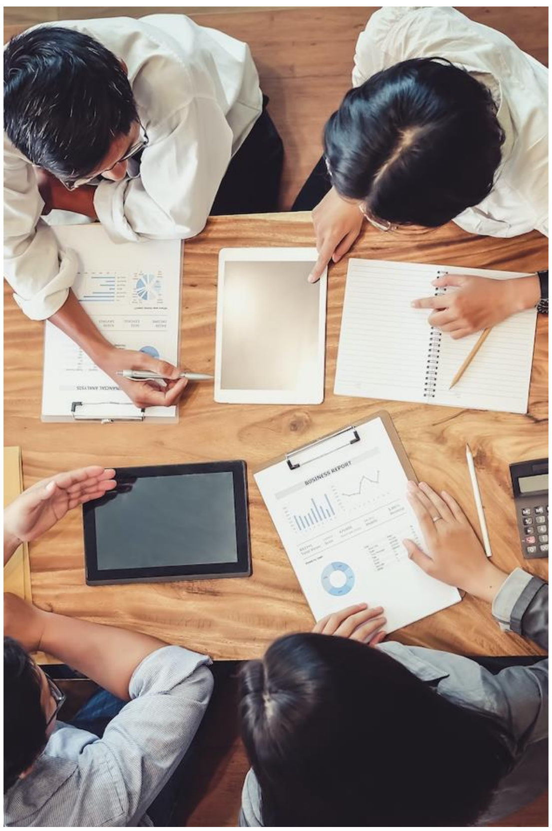
FCC Database Intersects with Federal Funding

The broadband speeds reported and incorporated into the FCC maps have real-life implications. For example, the FCC cites to the statistics from the broadband databases when developing broadband policies or making decisions that impact rural broadband and thus those decisions may be made in reliance on inaccurate data.

The FCC database is often used to define where federal broadband grants can or cannot be awarded. Areas with overstated speeds in the FCC maps are excluded from being eligible for federal grant funding.

[26] https://www.fiercetelecom.com/telecom/fcc-locks-key-vendor-broadband-map-revamp

Should DSL Qualify as Broadband?



The discussion paper reaches the conclusion, for a wide variety of reasons, that DSL technology delivered over a single pair of copper wires should not be considered in future broadband expansion plans as a viable technology. The subsequent section of the whitepaper examines whether DSL delivers service at the 25/3 Mbps as required by the FCC.

Theoretical or Ideal Speeds

Figure 2 compared the ideal speed of various types of DSL when transmitted on a single twisted pair of ideal copper wires. Figure 2 showed that VDSL2 may deliver download speeds faster than 25 Mbps approximately 1,000 feet from a DSLAM. Figure # shows that ADSL2+ may deliver download speeds a little greater than 25 Mbps approximately 2,000 feet from a DSLAM. For both DSL technologies, the ideal speed on a single copper wire drops below 25 Mbps after a short distance.

The fastest upload speed possible for ADSL2+ has been set by the vendors at about 1.5 Mbps. VDSL2 upload speeds may be as fast as the download speeds – in a lab setting. Vendors maximized the download link at the expense of the upload link, so there are very few brands of VDSL2 that deliver speeds faster than the FCC's definition of 3 Mbps upload, even for short distances.

The speeds of bonded DSL on two pairs of twisted wire are nearly double the speeds of single-pair DSL. Bonded DSL can also achieve the FCC's 3 Mbps upload test for a few thousand feet – depending on the specific upload of a given brand and version of DSL.

DSL Speeds Reported by Telephone Companies

Another way to understand actual DSL speeds is to look at the way that AT&T reports DSL speeds to the FCC. Based on a review of the FCC database for Dallas, TX, AT&T reports a wide range of DSL performance where DSL download speeds are reported as 1 Mbps, 3 Mbps, 6 Mbps, 9 Mbps, 12 Mbps, 15 Mbps, and 18 Mbps. AT&T reports some parts of Dallas with DSL speeds as fast as 40 Mbps – indicating bonded DSL with two twisted pairs.

Based on the FCC database, it is clear that AT&T operates a wide range of DSL technologies from the early ADSL varieties up to ADSL2+ and maybe VDSL2. Second, the slower speeds likely reflect the distance between a given neighborhood and the nearest DSLAM. The FCC data indicates that any single twisted pair DSL in Dallas operated by AT&T meets the FCC's 25/3 Mbps definition of broadband.

Even where AT&T is reporting bonded DSL, there are no parts of Dallas where AT&T is claiming download speeds faster than 40 Mbps – and some areas claim speeds of only 30 Mbps. Given the variation between ideal speeds and actual speeds reported by AT&T, one can draw a conclusion that DSL may not achieve ideal performance as identified in Figure 2.

Real-life speeds are at best some fraction of theoretical speeds – and that fraction is determined by the quality of the copper and the distance between customers and the DSLAM.

State-Sponsored Speed Tests

Many states, including South Carolina, request citizens take a home Speed Test. Speed Tests may provide a measure of the quality of broadband; however, Speed Tests are not 100% reliable. In spite of Speed Test limitations, certain states have found that when Speed Tests are administered en masse, a good picture emerged of the overall quality of broadband.

Only a few states post the results of speed tests for the public to review. Table 2 reflects the speed test data for a county in Wisconsin. The speeds in Table 2 represent the average speed test results for both download and upload by ISP.

Table 2

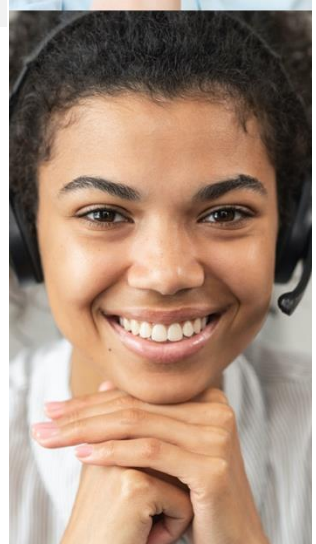
	Technology	Tests	Download (Mbps)	Upload (Mbps)
Charter	Cable Modem	11,844	67.06	9.82
CenturyLink	DSL	472	12.14	2.47
Frontier	DSL	1,193	7.25	0.93
Local WISP	Fixed Wireless	5,493	4.61	1.99
Satellite	Satellite	515	12.60	1.53
Cellular Hotspots	Cellular	106	18.32	2.25

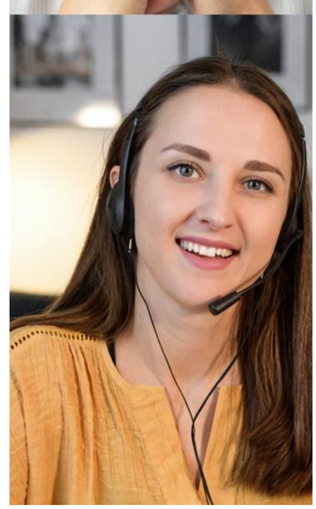
In aggregate, the average speeds experienced by customers in INSERT COUNTY, WI are significantly below the FCC's definition of broadband. Speed tests typically show DSL with download speeds in the range of 10 Mbps or less and upload speeds in the range of one or two Mbps.

Summary

The evidence from the various sources discussed all support the idea that single twisted pair DSL does not achieve the performance standards identified by the FCC for broadband. With the single exception of VDSL2 customers that live within 1,000 feet of a DSLAM, single twisted pair DSL may not be faster than 25 Mbps download and 3 Mbps upload.

Bonded DSL on two pairs of twisted wire may achieve the performance standards set by the FCC for broadband. Local conditions will dictate how far less than the ideal can be achieved in any given neighborhood.





Is the 25/3 Definition of Broadband Still Adequate?

A final question that is relevant to ask is whether the FCC's 25/3 Mbps definition of broadband is still valid. The discussion above considers DSL speeds using the 25/3 Mbps definition of broadband established in 2015. There is evidence that the FCC definition is out of date and out of touch with the real broadband world. Consider the following:

Parity Between Urban and Rural America

There is germane language in Section 706 of the Telecommunications Act of 1996 that suggests that broadband speeds in rural areas ought to be in parity with urban broadband speeds. The language from Congress says that the FCC "shall encourage the deployment on a reasonable and timely basis of advanced telecommunications capability to all Americans." The language using reference to all Americans has been widely interpreted over the years to mean that one of the tests for setting the definition of broadband speeds for rural America would be to set it in parity with the speeds available in urban areas.

In its Broadband Insights Report for the second quarter of 2021, OpenVault compared the percentage of broadband connections at various speed tiers for June 2020 and June 2021. The key takeaway from the table is that almost 80% of all U.S. households are now subscribed to broadband products with speeds of 100 Mbps or faster. The parity argument would suggest that this statistic alone would justify having a definition of download broadband of at least 100 Mbps download. The table also shows the rapid acceleration of households upgrading to faster broadband plans during the pandemic.

Table 3

% of Subscribers	June 2020	June 2021
Under 50 Mbps	18.4%	10.5%
50 - 99 Mbps	20.4%	9.6%
100 - 199 Mbps	37.8%	47.5%
200 - 499 Mbps	13.5%	17.2%
500 - 999 Mbps	5.0%	4.7%
1 Gbps	4.9%	10.5%

Speeds Required for Grants

Signals from government entities other than the FCC indicate that 25/3 should no longer be considered as the standard to determine whether an area is being served with broadband. For example, there are several current federal grant programs that suggest that the definition of broadband ought to be faster than 25/3 Mbps. The Rural Utility Service (RUS) recently released the grant rules for the Rural eConnectivity Program (commonly referred to as ReConnect grants). In this grant, the RUS is describing unserved households to be those with speeds under 25/3 Mbps. But the RUS is defining homes as underserved that have broadband speeds under 100/20 Mbps. Many in the industry are interpreting the new definition of underserved for grant purposes to be the equivalent of a new definition of broadband.

We also see the same definition of broadband being suggested by Congress. Grants from the Capital Projects Fund created by the American Rescue Plan Act (ARPA) also uses a speed of 100/20 Mbps to define underserved locations. Even more significantly, the newly enacted Infrastructure Investment and Jobs Act includes a $42.5 billion broadband grant program that also defines unserved as 25/3 Mbps and underserved as 100/20 Mbps.

While it is speculation at this point, there is an expectation that the definition of broadband should be increased to at least 100/20 Mbps. Such a change would raise an interesting question, because no DSL can achieve broadband speeds of 100/20 Mbps. If the FCC raises the definition of broadband to 100/20 Mbps, then DSL technology would clearly no longer be considered to be broadband.

Future Broadband Demand

It's well-understood in the industry that the demand for broadband speed and usage has grown steadily over time. The FCC first set the definition of broadband at 4/1 Mbps in 2010, and in five short years decided to increase the definition to 25/3 Mbps. It's now six years later and there is support in the industry to increase the definition of broadband to 100/20 Mbps. What might the definition need to be in another five or ten years from now?

In the late 1990s, when DSL was introduced to the mass market, the delivered speed was roughly 1 Mbps download. That felt blazingly fast at the time and was nearly twenty times faster than the dial-up technology that DSL was replacing. But it didn't take more than a few years for many homes to want something faster than 1 Mbps DSL. When Google Fiber introduced gigabit fiber in 2011, the technology was also nearly twenty times faster than the typical cable broadband connection at the time. We now see over 10% of all broadband customers nationwide subscribed to a gigabit broadband product. Broadband demand and usage grow steadily and will eventually grow to fill faster technologies.

It's not easy to measure the demand for speed on a large scale across millions of households. But we do measure broadband utilization – the amount of broadband used by homes – and that is a good surrogate to understand the growth in broadband demand over time. The firm OpenVault measures total broadband usage by households using software deployed by the biggest ISPs around the country and around the world. Consider the following statistics that show the U.S. national average monthly broadband usage by homes. These numbers combine download and upload usage.

1st Quarter 2018	**215 Gigabytes**
1st Quarter 2019	**274 Gigabytes**
1st Quarter 2020	**403 Gigabytes**
1st Quarter 2021	**462 Gigabytes**

This data shows extraordinary growth in the average use of broadband across the county. From the first quarter of 2018 to the first quarter of 2019, the average use of household broadband grew by 27%. Usage skyrocketed during the pandemic. From the first quarter of 2019 to the first quarter of 2020, during the pandemic, the average use of household broadband grew by an astonishing 47%. During the pandemic in 2020, the average household broadband usage grew by another 20%. The growth rate since 2018 is only slightly faster than the growth rate experienced over the last two decades - the industry has routinely seen broadband usage double roughly every three years.

What does this kind of growth mean? One way to think about broadband is by thinking about what broadband growth means to your neighborhood. Suppose you are served by DSL. If your ISP has the same number of customers in your neighborhood now as in 2018, the local network is now twice as busy, carrying twice as much traffic as just three years earlier. If your ISP hasn't made any upgrades during that time, the chances are that you can see signs of a stressed network. The extra usage means there is more demand on the total bandwidth provided to the neighborhood. This probably means a slowdown during busy times like during the evening prime time. It probably means it is harder over time to connect and stay connected to a work or school server or to a Zoom call.

Perhaps the most interesting way to put broadband growth into perspective is to look into the future. What happens if usage continues to double every three years? There is no reason to think it won't because we are finding more ways every day to use broadband. If broadband keeps growing at the historical rate, then in ten years, your neighborhood network will be carrying ten times more traffic than today. In twenty years, it will be carrying one hundred times more traffic than today.

When you think of growth in this manner, it's easy to understand why DSL networks are already overwhelmed and struggling – the networks are carrying far more broadband than was anticipated when they were designed. Looking at growth from this perspective explains why AT&T made the decision in 2020 to stop connecting new DSL customers.[27] Even if a telephone executive was to argue that DSL is still a broadband technology, they will clearly not be able to make this claim in ten years when networks are carrying ten times more data than today.

[27] https://arstechnica.com/tech-policy/2020/10/life-in-atts-slow-lane-millions-left-without-fiber-as-company-kills-dsl/

For policy makers there is one inescapable conclusion:

it is extremely important to efficiently use funding to build future proof broadband infrastructure.

Conclusion

This discussion paper reaches the conclusion that DSL technology delivered over a single pair of copper wires should not be considered in future broadband expansion plans as a viable technology and cannot reliably deliver speeds of 25/3 Mbps. This is an important conclusion because, in South Carolina, 355,550 households are still receiving broadband using DSL technology.[28]

Perhaps the biggest challenge for DSL technology came during the pandemic when it became clear that DSL could not satisfy the needs for employees and students to work remotely. The vast majority of DSL upload speeds are less than 3 Mbps, which is inadequate to support multiple people working from a broadband connection at the same time. Further, the older copper networks became quickly overwhelmed by the sheer volumes of broadband that hit all broadband networks throughout the daytime.

The paper reviews broadband trends in the industry, particularly those related to broadband speeds. Recent federal and state grant programs suggest that the current definition of broadband should be at least 100/20 Mbps. We also know that the amount of broadband usage at homes has been steadily doubling roughly every three years. Finally, we can see from recent data gathered by OpenVault that almost 80% of homes in the country are now subscribed to broadband products of 100 Mbps download or faster. For policy makers there is one inescapable conclusion: it is extremely important to efficiently use funding to build future proof broadband infrastructure.

[28] SC Broadband Office