Fiber Broadband Scalability and Longevity

TRUSTED TECHNOLOGY WITH NO EXPIRATION DATE

FIBER BROADBAND ASSOCIATION
TECHNOLOGY COMMITTEE
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Fiber Broadband ASSOCIATION

When fiber leads, the future follows.

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INTRODUCTION

Since the dawn of the internet in the early 1990s, internet speeds have increased by over 1,000 times and there is no end in sight to this growth.[1] Future decades will bring even greater demands from applications we may not envision today, requiring speeds of 10s or even 100s of Gigabits per second. Broadband infrastructure investments should be scalable and durable to keep pace with decades of growing demand.

Wireless, DOCSIS, and DSL technologies have required continuous outdoor infrastructure upgrades to increase speeds and capacity, and carriers have recognized the value of fiber as these incremental approaches typically include more optical fiber deeper into the network toward the subscriber. Fiber Broadband to each subscriber, by contrast, is the only communications technology that can support decades of speed and capacity increases with no upgrades to the outdoor infrastructure. The scalability of today's optical fiber to support higher speeds is virtually unlimited, to speeds 60,000 times higher than today's 10 Gigabit per second (Gbps) systems to individual homes or businesses. The longevity of fiber optic cabling infrastructure has already exceeded 35 years since the first deployments and we expect the average lifetime will be much longer than 35 years based on the materials, technologies, and manufacturing processes used to produce modern, high quality optical fiber and fiber optic cable. In summary, quality optical fiber and fiber optic cable have no known expiration date.

Fiber scalability and longevity are intensely technical topics. This paper is an attempt to condense many of the main topics into a readable form. However, FBA strongly recommends the reader also visit the supporting references provided.

[1] https://futuretimeline.net/data-trends/2050-future-internet-speed-predictions.htm

FIBER BROADBAND SCALABILITY

Today, Gigabit and multi-Gigabit symmetrical services are widely available to the half of America that has access to fiber broadband, enabling the fast and low latency speeds people need for today's entertainment, business, remote working, education, and health care applications. As these applications are improved over the next decade by virtual reality, mixed reality, augmented reality, AI, and emerging spatial computing, homes will need multi-gigabit low-latency services.[2]

The capacity and scalability of fiber are only limited by the equipment transmitting and receiving information at either end of the fiber cable link. Fiber broadband data rates continue to grow as the transmitting/receiving equipment continues to improve. Commercial FTTH deployments started with ATM Passive Optical Network (A-PON) equipment delivering 155 Megabit per second (Mbps) speeds in the early 2000s. In 2023, 100 Gbps FTTH systems were launched, 645x faster than 20 years ago, yet can operate over the same optical fiber deployed in the 1980s.

We don't yet know the absolute capacity of optical fiber itself. An estimate of the ultimate capacity in a single strand of standard G.652.D-type single-mode fiber in an access application is over 600 terabits per second, or roughly 60,000 times the speed of today's XGS-PON (10 Gbps) networks.

This number is derived by multiplying the optical spectrum (1260 nm to 1650 nm, or 51.144 THz) by a spectral efficiency factor of 12 bits/s/Hz.[3] Viewed another way, optical fiber deployed today in the access network is only using about 1/60,000 of its known capacity. No other wired or wireless communications medium can come close to this capacity.

In this paper, "infrastructure" is defined as the outdoor communications infrastructure in the access part of the network between the central office and the subscriber location. The infrastructure for wireless, DSL, and DOCSIS HFC networks consists of many powered nodes that are typically upgraded to support higher speeds, and these upgrades often require additional new powered nodes and additional fiber optic cabling to the nodes.

[2] "Fiber Broadband can Close the North American Rural Digital Divide" – Fiber Broadband Association, June 2021

[3] Capacity Trends and Limits of Optical Communication Networks, Rene ́– Jean Essiambre, Senior Member IEEE, and Robert W. Tkach, Fellow IEEE, Vol. 100, No. 5, May 2012 | Proceedings of the IEEE.

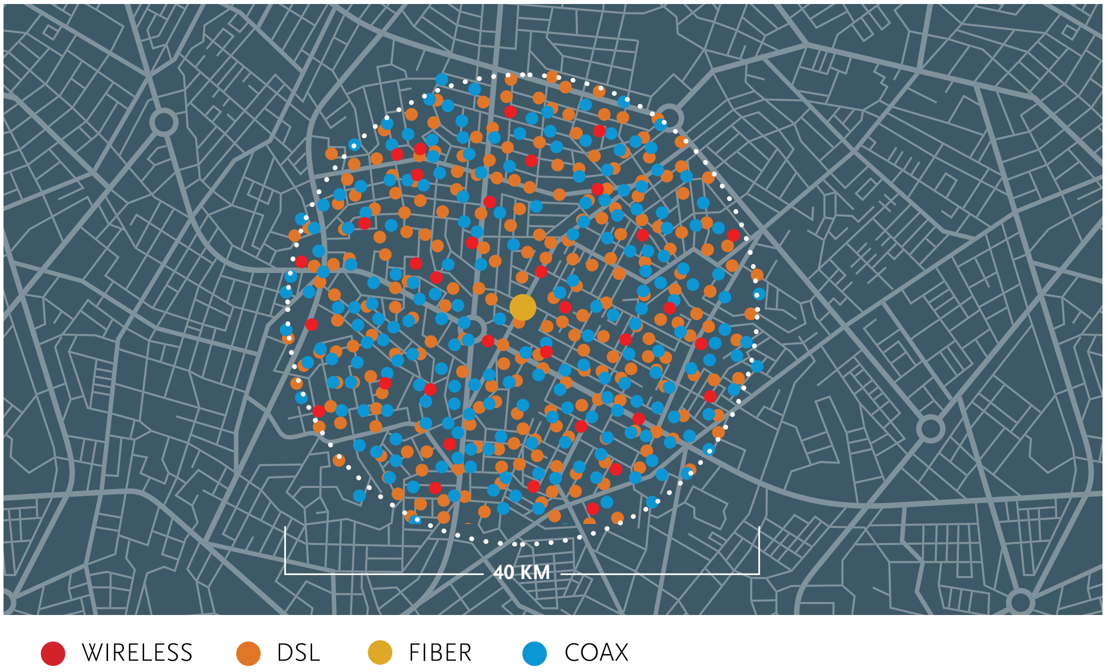

Fig 1: Outside Powered Nodes for Fiber Broadband, DSL, HFC, and Wireless (Source: OFS)

Wireless has required multiple infrastructure upgrades from 1G to 5G[4], and 6G is next. DOCSIS has required multiple infrastructure upgrades from DOCSIS 1.0 to DOCSIS 4.0.[5] DSL reached its limit and is being quickly replaced by fiber.[6] The same optical fiber infrastructure deployed 35 years ago supports yesterday's and today's systems. Optical fiber cabling is the only communications infrastructure that can support both existing and future applications for many decades with no changes.

[4] https://en.wikipedia.org/wiki/List_of_wireless_network_technologies
[5] https://en.wikipedia.org/wiki/DOCSIS
[6] https://www.bcg.com/publications/2021/copper-networks-fiber-optic-network-shift

Broadband infrastructure scalability should also consider latency, the delay time from the moment a user requests information until they receive the first response to that request. Applications including virtual reality, mixed reality, augmented reality, AI, and emerging spatial computing require low latency. Verizon has estimated that any more than 20 milliseconds (ms) of motion-to-photon (total stack) latency causes many users to become nauseated[7]; Latency will need to be reduced to the single to low-double digit milliseconds (ms), from its current level of 30-150 ms, Meta has said[8]. In addition to latency, jitter, the variation in latency, must also be minimized to improve end user experience.

Fiber broadband offers the best latency and jitter performance based on user measurements.

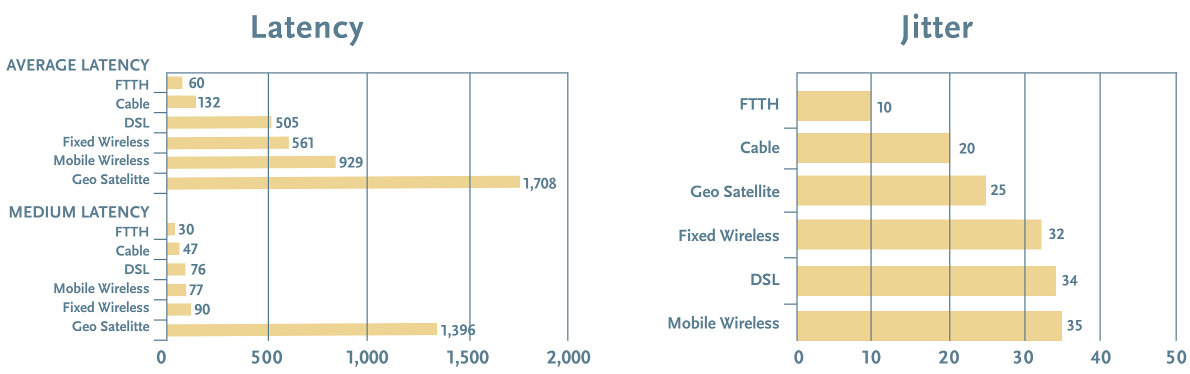

Fig 2: Latency and Jitter in milliseconds, FBA/ RVA LLC Consumer Broadband study, 2023

While we see in the FBA/RVA consumer broadband study that median latency for FTTH at 30 milliseconds is the lowest, most latency is caused by queuing at buffers in the network. The industry is working to reduce this buffer related delay by improving network congestion management. If we remove the latency contributed by queuing at buffers, FTTH offers the lowest potential infrastructure caused latency at 1.1 to 2.1 milliseconds, 48% to 72% better than the next best from Low Latency DOCSIS at 2.1 to 7.6 milliseconds.[9]

[7] https://www.credit-suisse.com/media/assets/corporate/docs/about-us/media/media-release/2022/03/metaverse-14032022.pdf
[8] https://www.telecompetitor.com/meta-faster-symmetrical-bandwidth-lower-latency-among-advances-needed-for-the-metaverse/
[9] https://www.bitag.org/documents/BITAG_latency_explained.pdf, Table 2 and Page 20

FIBER BROADBAND INFRASTRUCTURE LONGEVITY

Optical Fiber Mechanical Lifetime

Optical fiber is a very thin strand of glass (SiO_2), with a glass core doped with chemicals to increase the index of refraction so it can guide light, and a glass cladding outer layer of pure silica surrounded by acrylate polymer coatings, as shown in figure 3. The diameter of the cladding is 125 microns, only about double that of a human hair!

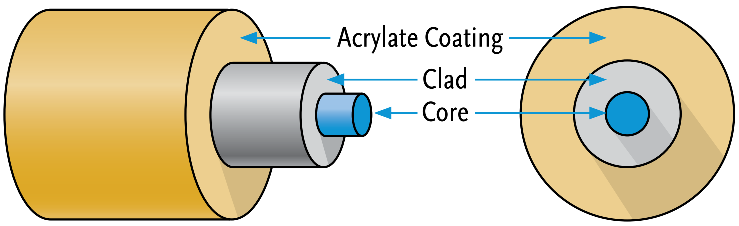

Fig 3: Optical Fiber (Source: OFS)

With the invention of low-loss optical fiber in the 1970s[10], a tremendous amount of research was conducted in the following 20 years to thoroughly understand and improve the optical and mechanical behavior of glass fibers in cable. This research was used to define industry standards that are used today for designing, manufacturing, installing, and operating fiber networks around the globe. This research serves as the foundation for the well-deserved reputation fiber has developed for reliability. The International Telecommunications Union (ITU) has published its Supplement 59, "Guidance on Optical Fiber and Cable Reliability," which summarizes guidance on long-term reliability for fibers in cable[11]. Most of the references cited in the ITU document (and in this paper) also cite many other references, which highlight the depth of research in fiber and cable reliability that has occurred over the past decades.

A key question often asked is "What is the lifetime of fiber?" A simple answer is when the fiber is properly designed, manufactured, cabled, and installed per standards and manufacturer recommendations, there are no inherent mechanisms that cause high-quality fiber (meeting FBA Trusted Fiber[12] guidelines) to spontaneously break or darken. A quality fiber optic cable manufacturing process adds the proper strength elements and a protective polyethylene outer jacket that together protect the optical fiber from the environment and excessive stresses, such that there is no defined lifetime or expiration date for such a fiber optic cable.

The design of the single-mode fiber type used for broadband networks deployed today is like that deployed in the 1980s, but the quality and performance have improved significantly since those first installations. Although 25 and 40-year lifetimes have been sometimes attributed to fiber, those lifetimes are driven by accounting depreciation schedules versus inherent degradation mechanisms. Other long-lived assets often have shorter depreciation schedules than operating lives.[13]

[10] https://ethw.org/Milestones:World%27s_First_Low-Loss_Optical_Fiber_for_Telecommunications,_1970
[11] https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-G.Sup59-201802-I!!PDF-E&type=items
[12] https://fiberbroadband.org/wp-content/uploads/2023/12/FBA-Trusted-Fiber-1.0-December-2023.pdf
[13] Publication 946 (2022), How To Depreciate Property | Internal Revenue Service (irs.gov)

Diameter to diameter, the pure flaw-free glass in quality optical fiber is about 10 times stronger than high strength steel, typically about 700,000 pounds/square inch (PSI)[14], compared to 70,000-85,000 PSI for cold rolled steel.[15] The glass is so pure and strong it can be bent without breaking.

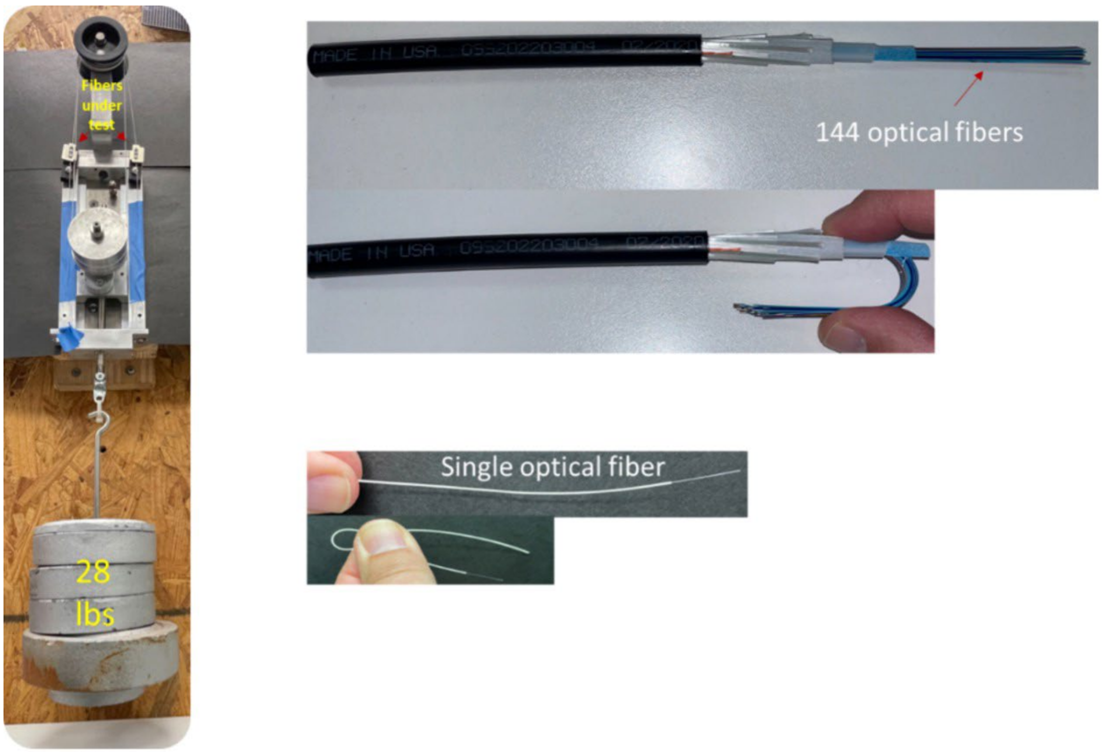

Fig 4: Optical Fiber's 700,000 PSI level of strength is shown, where two optical fibers are holding 28 lbs. of weight. Optical fiber's bendability is demonstrated. (Source: OFS)

Although the very pure glass in optical fiber is very strong and flexible, like any material, optical fiber is only as strong as its weakest link. Impurities or other mechanical flaws in the glass, even as small as fractions of a micron, can weaken it.

Even though the starting glass is processed in a clean room, there are chances for flaws, such as mechanical abrasions or particulate inclusions, to be added during the manufacturing process. For that reason, after fiber is drawn, there is a manufacturing step called "proof testing." It is a "go/no go" tensile test and is used to remove flaws that are weakest links in the fiber. This test is typically performed to 100,000 pounds per square inch (100 KPSI), but may be higher for special applications, such as undersea networks. If the fiber survives the test, it is deemed strong enough to be placed into some type of cable. The proof test itself is simple. Fiber is typically guided around a pulley with a weight attached to it (around 2 lbs for 100 KPSI). Today's 100 KPSI number is a result of research that occurred primarily during the 1980s, when the proof test was increased from an original 50 KPSI level. Due to the proof test, fiber has a minimum strength (100 KPSI) after original manufacturing.

[14] THE RELIABILITY OF OPTICAL FIBERS AND PASSIVE FIBER COMPONENTS IN LONG AND SHORT COMMUNICATION NETWORKS - International Wire and Cable Symposium, 2014

[15] https://en.wikipedia.org/wiki/Cold-formed_steel

An important question is how much tension can be applied to a fiber without causing flaws remaining in the fiber to grow and weaken the glass over time.

Limiting fiber strain prevents flaws in the fibers from growing and is a main reason why fiber has achieved its stellar reputation for reliability. This is done by providing a recommended maximum cable application tension, which correlates to less than 0.2% strain (stretching) on an individual fiber in the cable.[16] Limiting the application tension is achieved by properly designing, manufacturing, and installing fiber optic cables to ensure flaws do not grow over the lifetime of the cable. For example, with many duct cables, the tension limit is 200 lbs. long-term load. Other cable designs may have higher or lower tension limits, depending on the application. Limiting fiber strain and application tension during installation and long-term operation has proven very effective for long-term reliability of fiber optic cables.

Fiber Optic Cable Lifetime

Reputable optical fiber within the proper fiber optic cable design can be expected to last for decades. In manufacturing fiber optic cable, optical fibers are surrounded by materials protecting optical fiber from the environment and excessive strain to assure it will function properly for many decades. The figure below shows an example of a modern fiber optic cable design consisting of a water blocking tape that prevents moisture contact with the fibers, central core tube, fiberglass rods which add tensile strength, optional steel armor to resist rodent damage, and a polyethylene outer protective jacket.

A critically important component is the outer jacket. If the outer jacket is breached, water can seep in and freeze, potentially causing attenuation or even breaking fibers. On the other hand, if the jacket remains intact, it can provide very effective protection of the fibers inside. Fortunately, the most common outer jacket material of fiber optic cables is polyethylene, a proven highly durable material.

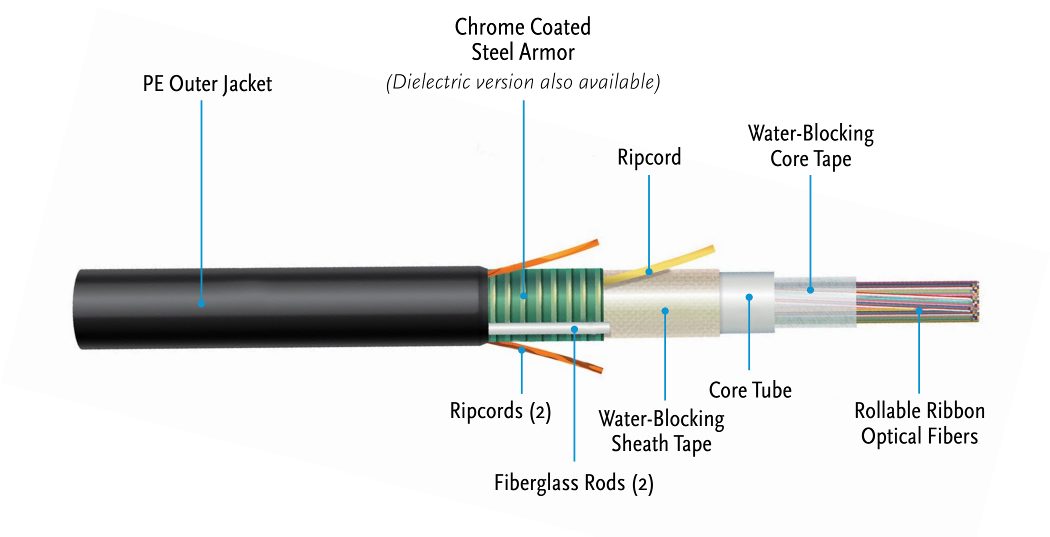

Fig 5: Fiber Optical Cable Construction (Source: OFS)

[16] "Design methodology for the mechanical reliability of optical fiber" Glaesemann, Gulati, Corning, Optical Engineering, June 1991

Polyethylene (PE) was first discovered by accident in 1898 and again in 1933,[17] and has been used as a cable jacketing material for many decades. Unprotected polyethylene can be broken down and embrittled by UV radiation such as sunlight through the process of photo-oxidation, but the addition of carbon black of specific size and concentration arrests that reaction, enabling a multi-decade lifetime and preserving flexibility.[18] The chemistry and subsequent product performance of polyethylene have been studied and refined since the 1950s.[19]

Polyethylene in pipes has an estimated half-life of 1,200 years. Although the polyethylene layer in fiber optic cables is thinner than that of pipes, the projection underscores the expected longevity of polyethylene in either aerial or buried environments.[20] Copper cabling in various scenarios has lasted more than 80 years with the same type of polyethylene sheath used with modern fiber optic cables. Optical fiber doesn't experience the same failure modes as copper, such as corrosion. Without those failure modes, it's reasonable to expect the fiber infrastructure to last longer than the previous copper infrastructure.

A recent quote from a cable R&D engineer sums up the role of polyethylene in today's fiber optic cables: "We don't know when jackets with 2.6% N110 black will degrade…they have not existed long enough for us to find out yet. Current modern black PE jackets for aerial optical cable will almost certainly be fine long after we're all dead."[21] As with optical fiber, the industry has developed standards and testing requirements for fiber optic cable.[22] The tests include accelerated aging, temperature cycling, impact, tensile testing, twisting, and many other tests that stress the cable as it might experience throughout its lifetime. These standards have been updated over many decades to assure that compliant trusted fiber optic cables will perform as intended during installation and long-life operation in the field.

Installation and Operational Practices Preserve Fiber and Cable Lifetime

Proper installation and operational practices are critical to preserving fiber and cable lifetime. Improperly installed cables or cables installed in applications or environments not specified for the cables may exhibit problems and premature failure.

Assuming the cable is properly installed in an appropriate environment for its application, there are two main factors affecting the longevity of the installation. As previously discussed, observing maximum installation tension rules is extremely important for long fiber lifetimes by limiting the strain experienced by the fibers. The second main factor is observing minimum bend radius guidelines for the cable in question. Bending guidelines vary from cable design to cable design. If cables are bent tighter than the manufacturer's specified minimum, attenuation and possibly fiber breakage can result. Other factors, such as observing twisting guidelines and not abrading the cable jacket are also important.

17 https://plastics.syr.edu/page.php?id=/materials/polyethylene-pe#:~:text=Polyethylene%20was%20first%20synthesized%20by,chains%20and%20termed%20it%20polymethylene

18 "Weathering Studies on Polyethylene, Wire and cable applications", V. T. WALLDER, W. J. CLARKE, J. B. DeCOSTE, AND J. B. HOWARD, Bell Telephone Laboratories, Inc., Murray Hill, NJ, Industrial and Engineering Chemistry, Nov. 1950

19 Some Observations on the LongTerm Behavior of Stabilized Polyethylene J. B. HOWARD and H. M. GILROY Bell Laboratories, Murray Hill, NJ, POLYMER ENGINEERING AND SCIENCE, APRIL, 1975, Vol. IS, No. 4

20 https://pubs.acs.org/doi/pdf/10.1021/acssuschemeng.9b06635

21 Internal presentation – OFS

22 ICEA S-87-640, 7th Edition, 2023 – Standard for Optical Fiber Outside Plant Communications Cable

Fiber optic cables are installed aerially or underground, either direct-buried or in conduit. The expected lifetime of these installation methods is similar. However, since all rights of way are different, actual reliability will be different. Underground installations are typically thought of as being more reliable. However, in areas with frequent growth and construction, underground cables can be dug up. Likewise, aerial rights of way are often thought of as being less reliable, and certainly areas with significant gunshot or weather activity can prove that out. However, there can be aerial rights of way that are also very reliable.

If installation issues or damage does affect a fiber optic cable, it's isolated to very short sections of the fiber optic cable infrastructure and can be quickly repaired. The important point is that these external factors may determine the lifetime of a particular short fiber optic cable segment, but quality fiber optic cable installations are expected to last much longer than the 35 years we have observed to date.

Real World Examples

Fiber's longevity is not just theoretical. Service providers that installed fiber optic cable decades ago are still using those same cables to support high-speed communications today.

Fiber service provider altafiber deployed fiber optic cables as early as 1990 to support early megabits per second data rates. **Those same fiber optic cables, 34 years later, are today supporting 10 Gbps and faster services, as well as multiple wavelengths.** These cables are deployed in both aerial and underground environments. Today, altafiber passes over 1 million homes and businesses with high-speed fiber internet services across its Greater Cincinnati and Hawaii markets and continues to expand its successful FTTH network.

TDS Telecommunications is ramping up its fiber deployment with the goal of 1.2 million marketable fiber service addresses by 2026. Its expansion efforts include overbuilding its legacy telephone and cable markets and entering new communities mainly in Wisconsin and the Pacific Northwest. For residential customers, TDS is offering 8 Gigabit speeds in certain markets and is seeing growth in customer take rates on higher speeds with 14% of its customer base on 1 Gigabit or higher. **TDS has always supported efficient use of existing facilities and as such has a working 36-year-old underground fiber optic cable placed in 1988 that currently supports a transport system utilizing multiple 100 Gbps wavelengths.** The other TDS fiber optic cables placed shortly after 1988 also continue in operation.

Similar examples as altafiber and TDS exist in North America and around the world.

SUMMARY

Optical fiber is the only communications medium that can support both existing and future applications for many decades with no changes to the infrastructure. The XGS-PON 10 Gb/s access networks deployed today are using a tiny fraction (<0.002%) of an optical fiber's known available capacity, meaning that the same optical fiber installed today can support many decades of speed increases. Fiber Broadband systems additionally offer the lowest latency today and the lowest potential latency to support future latency sensitive applications including AR and VR.

Optical Fiber and fiber optic cable have been highly studied, understood, and improved through the years, and the industry has used this understanding to design and deploy optical fiber cabling networks with proven long-term reliability. Fiber optic cables have been in service for decades supporting speed increases from Megabits to Gigabits per second on the same cable, with the potential to support Terabit per second speeds in the future. Modern, trusted optical fiber and fiber optic cable have no known expiration date. With fiber, the future is quite bright indeed.