REYNOLDSBURG OHIO

FIBER TO THE PREMISES STUDY

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Reynoldsburg
OHIO · 1839

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FTTP STUDY

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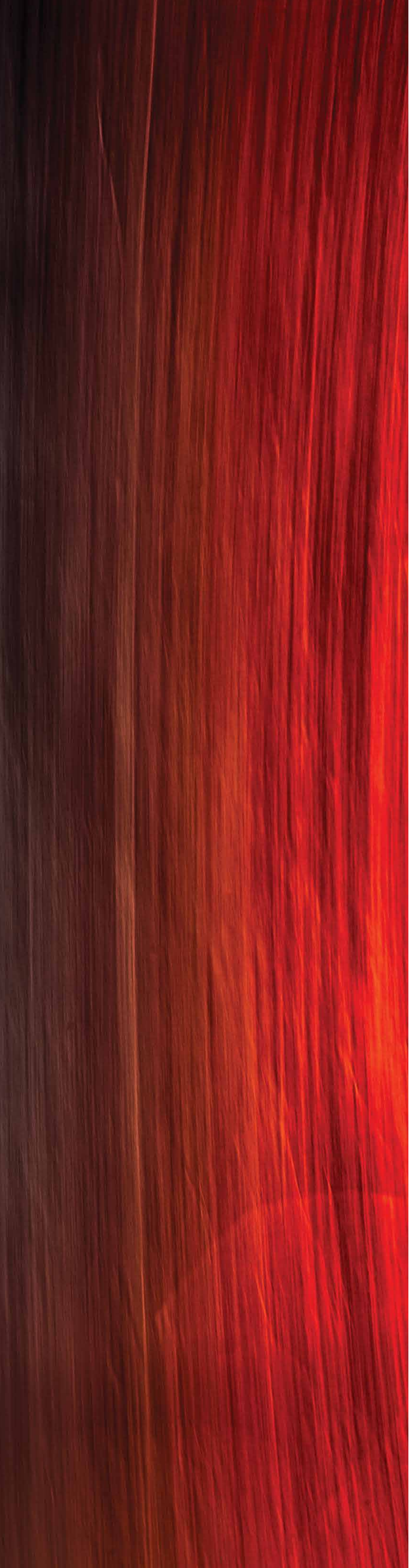

FTTP STUDY

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EXECUTIVE SUMMARY

This study examines the broadband service alternatives in Reynoldsburg, OH, focusing on Fiber to the Premises (FTTP) technology. The analysis covers the scope, types of PON systems, comparative analysis of access technologies, users' current and future needs, FTTP deployments in the United States, and additional key considerations. The objective is to evaluate the feasibility and potential benefits of implementing FTTP in Reynoldsburg.

The study begins by exploring various broadband service alternatives available, including DSL, cable modem, FTTP, terrestrial wireless, and satellite service. It provides a comparative analysis of these technologies to understand their advantages and drawbacks.

In-depth research is conducted on FTTP technology, its scope, and different types of PON systems, such as "10 Gig" PON. The study emphasizes the potential of FTTP to meet the increasing demand for high-speed and reliable broadband connectivity.

To make an informed decision, a comparative analysis of access technologies is performed, considering factors like speed, reliability, and scalability. The findings highlight the advantages of FTTP over other alternatives. Users' bandwidth requirements, both present and future, are analyzed, considering the growing demand for high-bandwidth applications. This emphasizes the need for a robust and future-proof infrastructure like FTTP.

Successful FTTP deployments in the United States, including case studies of Verizon Fios, AT&T U-VERSE/GPON, and others, provide insights into implementation feasibility and potential challenges in Reynoldsburg. Examining the current broadband market share in the United States helps identify dominant players and their positions, providing context for potential FTTP implementation opportunities in Reynoldsburg.

The study assesses expected advancements and emerging technologies in the broadband industry to evaluate the long-term viability and competitiveness of FTTP in Reynoldsburg. The local context of FTTP activity in Ohio is examined to evaluate the regional feasibility of implementation in Reynoldsburg.

Analysis of current broadband suppliers in Reynoldsburg helps assess existing infrastructure and competition, providing insights into potential partnerships and market dynamics. Based on the analysis, a recommended FTTP architecture and assumptions are provided to meet the specific needs of Reynoldsburg. A financial feasibility analysis estimates project costs, including infrastructure, equipment, installation, and labor, helping stakeholders understand the financial implications.

An estimated project timeline outlines different stages, ensuring a smooth and timely execution of the FTTP implementation. Different business models, such as build/own/operate, public-private partnerships, and open access, are evaluated to determine the most suitable approach for Reynoldsburg. Potential partners, including ISPs, infrastructure providers, technology vendors, and local authorities, are identified and assessed for collaboration to streamline the implementation process.

Based on comprehensive analysis, key findings and recommendations support the implementation of FTTP as a reliable, high-speed, and future-proof solution for Reynoldsburg, meeting the community's growing demands.

In conclusion, implementing FTTP in Reynoldsburg, OH, holds significant potential for enhancing broadband infrastructure and meeting the evolving needs of the community. The analysis presented in this study provides a robust foundation for making informed decisions regarding FTTP implementation.

1 BROADBAND SERVICE ALTERNATIVES

1.1 SCOPE

This study examines Broadband Services for residential and small business users. Residential and small business users have unique needs and challenges, including limited budgets and the requirement for reliable high-speed connections. Large businesses, government organizations, and educational institutions operate on a different scale and use different technologies, making them outside the scope of this study. By narrowing the focus to residential and small business users, the study provides targeted insights and recommendations that address their specific concerns in FTTP deployment.

Furthermore, this study delves into the substantial potential benefits of FTTP technology in Reynoldsburg, OH. It possesses the capability to enhance the broadband infrastructure and effectively cater to the ever-evolving needs of the community.

1.2 INTRODUCTION

Broadband Services can be defined as providing users the ability to access a range of digital services through the Internet, whether it be email, communication services, streaming video, file access, or many other types of digital services.

There are five different methods of accessing the Internet for Broadband Services. Three of them use a wired connection while the other two use wireless technology.

Two of the wired alternatives leverage existing networks; copper-based (telephone networks) and coax-based (cable TV networks). The third wired alternative, fiber-based, needs to be installed specifically for broadband service, which has historically put this alternative at a significant cost disadvantage.

The two wireless alternatives are terrestrial-based wireless and satellite-based wireless.

1.3 DSL SERVICE (COPPER-BASED)

The first residential data offerings were introduced by telephone companies to run over their existing telephone lines in the 1990s. Many variants of the basic technology, DSL, have been developed, and it is still a viable service at the lower end of the service spectrum. It operates at the lower end of the speed range but also at a typically lower cost. About 90% of US households have access to DSL services. Most of the larger players such as AT&T, Lumen, and Frontier offer services of up to 100 Mb/s.

The speed available to users with this technology varies inversely with the distance from the premise to the operator's exchange. This makes the service problematic for rural applications, which typically have longer loop lengths. Some operators are phasing out their DSL offerings as they ramp up their fiber network.

1.4 CABLE MODEM SERVICE (COAX-BASED)

The cable network operators, commonly referred to as Multiple System Operators (MSOs), originally built their networks with coaxial cable which had enough bandwidth to carry linear television channels. Every quarter of a mile or so, the signal needed to be amplified, which added noise so that the further down the chain subscribers were, the more the signal degraded.

In addition, an amplifier failure at any point in the link shut off service to everyone down the chain from that point, so cable networks rightly had a reputation for poor quality and reliability. The MSOs solved this once optical technology became cost-effective, by running fiber part-way to the customer and only using amplifiers for the last mile or so. This created the concept of hybrid fiber-coax (HFC), which has stuck as a name for this type of network.

As the service set expanded over time to include interactive video, voice, and broadband data, the HFC networks had to be modified to support these two-way services. The US MSOs created a jointly owned entity, CableLabs, to specify new services and network capability and also to provide vendor certification for the specs to ensure both low cost and interoperability. This process has been extremely successful and has since been expanded to include operators from all around the globe.

For broadband data, the CableLabs specification is known as Data Over Cable Service Interface Specifications or DOCSIS. The first specs were released in 1997 and have grown in capability and sophistication ever since.

The current specification is DOCSIS 3.1, which provides a shared 10Gb/s Gigabit downstream capacity and shared 1Gb/s capacity upstream. This allows the MSOs to offer 1 Gb/s service to their users. DOCSIS 3.1 has been widely deployed, and as a result, the MSOs currently enjoy about a 70% market share in the US for residential data.

Recognizing the threat of fiber to the home systems, CableLabs is currently working to increase system capacity to support 10Gb/s service in the future.

1.5 FTTP SERVICE (FIBER-BASED)

This method takes fiber right to the subscriber's premise. The technology will be described in detail in the next Section.

1.6 TERRESTRIAL WIRELESS SERVICE AND SATELLITE SERVICE (WIRELESS-BASED)

There are two categories of wireless broadband offerings to be considered, namely those based on satellite technology and terrestrial wireless options.

Looking first at satellite technology, broadband data using satellite plays at best a niche role in the industry. Current offerings are limited in speed by the GEO satellite technology, despite ongoing improvements, and the user terminal, which must be mounted outside, is quite expensive. The advantage of satellite is its availability in places where wired connections cannot be provided. This includes not only the obvious rural locations but also pockets of sites within urban environments where access is difficult.

A new type of satellite deployment using a large number of satellites, at much lower orbits (LEO-based systems), is promising significant speed improvement, but the technology will remain limited in its ability to compete with existing broadband offerings.

There are two types of terrestrial wireless solutions available to provide broadband services. The first, known as Fixed Wireless Access (FWA), has been available in some limited areas for quite some time. The speed available is a function of the frequency used to make the connection. A number of systems have been deployed to date, but the main drawback, like satellite, is terminal cost and complexity, as well as the relatively short distance between operator antenna sites and users, depending on power budget and frequency.

The availability of licensed mid-band and millimeter wave spectrum has enabled 5G operators, which own this spectrum, to deploy higher bit rate systems, and operators such as T-Mobile and Verizon see a significant opportunity to provide a residential broadband service going forward with this technology.

Another terrestrial wireless option for residential customers is to use their 5G mobile broadband capability as a hotspot for their other devices and forgo any other residential broadband offering completely. Even with the significant increase in speed becoming available as 5G networks are built out, there is not nearly enough bandwidth available to support this type of offering on a broad basis. Operators will, therefore, likely limit their hotspot capability in terms of data caps and pricing plans to curtail the broad use of this option.

2 FTTP SCOPE AND DEFINITION

2.1 INTRODUCTION

Although Fiber to the Premise (FTTP) is being deployed on a worldwide basis, this report will look at deployments, lessons, competitive technology, and projected evolution of systems in the United States.

There are two fundamental types of architecture used by fiber-based systems, namely point-to-point (home run) and fiber split (PON) systems. Point-to-point systems, using a dedicated fiber to connect the network to each user, are commonly deployed for large users such as government, universities, hospitals, private enterprises, etc., but are impractical for residential deployment, from both a cost and operational perspective.

For residential and small business use, passive optical splitters are used to enable a number of users (typically 16 to 48) to share a fiber connection. These systems are referred to as Passive Optical Network (PON) systems. The architecture of such a system is shown in Figure 1. Optical equipment

(OLT) in the service provider's facility communicates over the fiber link with equipment at the subscribers' premise (ONT) to provide broadband services.

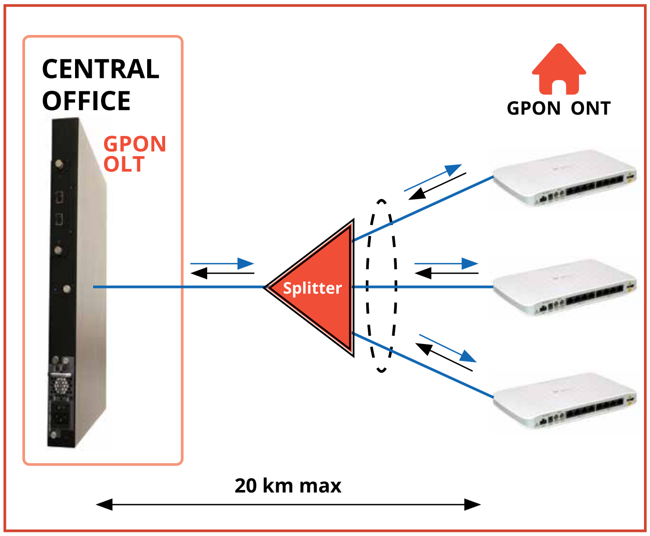


Figure 1. Components of GPON FTTP Network
Source: https://images.app.goo.gl/do9Cxz9hmHk3iyCa9

The basic premise is that each fiber within a bundle of fibers connecting the network to a community is shared by a number of locations. The sharing is accomplished by passive optical splitters that sit at operator-owned cabinets spaced throughout the neighborhoods. A unique attribute of these systems is that they are passive, i.e. not requiring power and hence no battery backup. This significantly simplifies the outside plant portion of the network versus copper or coax-based systems.

Downstream transmission which is "one to many" is relatively simple with all signals being encrypted and broadcast to every location, and each user is able to decrypt the subset intended for that location. This is similar to how the HFC-based systems of the cable operators work.

Upstream the "many to one" process is more complex, so Time Division Multiplexing (TDM) is used to give each user a slot in which to transmit.

Architecturally, these PON systems are quite simple with no active electronics or power required in the outside plant portion of the network and simple digital signaling used in both directions.

Since fiber is being used as the transmission medium all the way from the network operator's facility to the end user, these networks are commonly referred to as Fiber-to-the-Premise (FTTP) networks.

2.2 TYPES OF PON SYSTEMS

As the optical technology driving long-haul high-speed transport for commercial use has matured, it has migrated down to enable low-cost optoelectronic transmitters and receivers for use in residential and small business networks.

Global standards have been developed by both the International Telecommunications Union (ITU) and IEEE since the introduction of PON technology. Figure 2 summarizes the types of PONs standardized for use today and being developed for future use.

The first version of standardized PON was based upon using Asynchronous Transfer Mode (ATM). As ATM fell out of favor a new version of the specification known as Broadband PON or BPON was standardized as ITU-T G.983, and about 10 million lines of this type of PON have been deployed worldwide. Verizon used this type of PON for their initial FiOS system, the first large-scale PON deployment in the US. As the internet and resultant Internet Protocol (IP) signaling grew in importance, Verizon migrated to a newer technology known as GPON, designated as ITU-T G.984. This is the dominant system in use within the US today. It is a proven, mature technology.

All PON systems use single-mode fiber and have separate optical wavelengths (think colors) for downstream and upstream communication. For GPON systems, the downstream wavelength is 1490 nm, and the upstream wavelength is 1310 nm. The payload for GPON downstream is 2.4 Gbits per second and the upstream payload is 1.2 Gbits per second.

In parallel, the IEEE has standardized a PON optimized for ethernet transport, known as EPON, designated as 802.3ah. This technology is widely deployed in many countries in Europe and Asia but has very little deployment in the US. A potential future use of this technology in the US would be from the cable operators, or MSOs, if they decide to move to FTTP rather than continuing to evolve their HFC-based DOCSIS systems.

	PON Name	Standards Body	Designation	Intro Year	D/S Speed	U/S Speed	Current Status
1.	BPON	ITU	G.983	1998	622Mb/s	155Mb/s	Replaced by GPON
2.	**GPON**	ITU	G.984	2003	2.5Gb/s	1.25Gb/s	Millions deployed
3.	EPON	IEEE	802.3ah	2004	1Gb/s	1Gb/s	Europe and Asia
4.	ION-EPON	IEEE	802.3av	2009	10Gb/s	10Gb/s	Europe and Asia
5.	XG-PON	ITU	G.987	2010	10Gb/s	10Gb/s	Replaced by XGS-PON
6.	NG-PON2	ITU	G.989	2014	4 x 10Gb/s	4 x 10Gb/s	Trials
7.	**XGS-PON**	ITU	G.9807	2015	10Gb/s	10Gb/s	Ramping up
8.	NG-EPON	IEEE	802.3ca	In progress	25 or 50Gb/s	25 or 50Gb/s	—
9.	G5p.x	ITU	g.hsp.x	In progress	25+Gb/s	25+Gb/s	—

Figure 2. **Types of Passive Optical Networks (PONs)**

2.3 "10 GIG" PON SYSTEMS

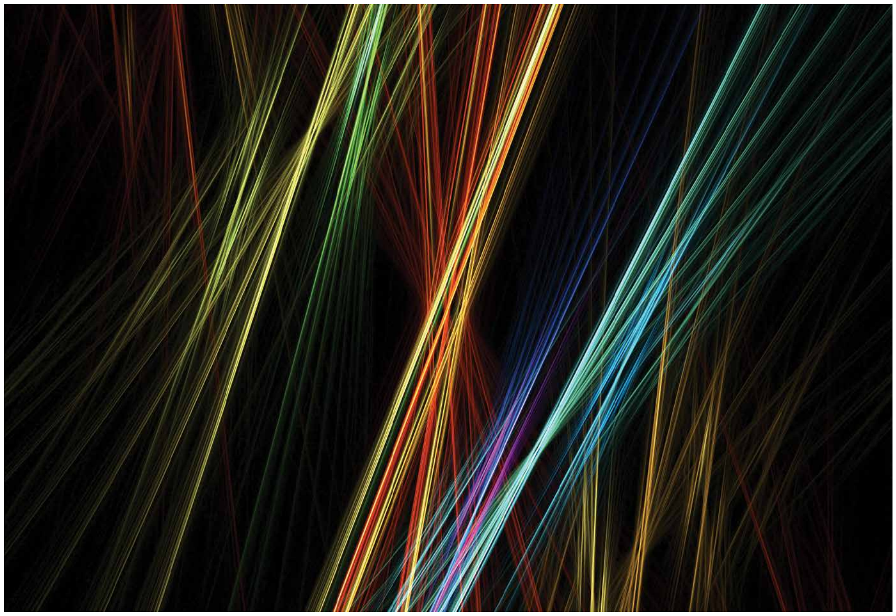
As demand for broadband speed continues to grow, both ITU and IEEE have standardized several new systems capable of 10 Gb/s speeds in both directions. The same process of technology migration from long-haul commercial fiber networks is driving the 10Gig transmitters and receivers necessary for these new PONs. Building on GPON, types of 10G PONs have been standardized, each targeting a separate market segment. The first, XGS-PON, is the simpler of the two, being architecturally identical to GPON, with the same 20 km reach, using two new optical wavelengths (1577 nm downstream and 1270 nm upstream). This enables both GPON and XGS-PON to run at the same time over the same infrastructure, allowing a seamless upgrade for operators already deploying GPON. The second, NG-PON 2, uses a more complex architecture and more sophisticated technologies, such as tunable lasers, running multiple wavelengths in each direction to increase capacity.

NG-PON 2 has so far only been deployed by Verizon. They have taken a holistic approach to fiber deployment, using a single system to serve not only FTTP applications but also their large business customers and their extensive fiber deployment supporting their 5G wireless rollout. XGS-PON, on the other hand, has rapidly supplanted GPON as the technology of choice for most new PON build-outs.

2.4 FUTURE EVOLUTION

Work is also underway on yet higher-speed systems at 25 Gb/s or 50 Gb/s capacity, ensuring the long-term viability of fiber-based networks.

3 COMPARATIVE ANALYSIS



COMPARING ACCESS TECHNOLOGIES

To make a meaningful comparison between the strengths and weaknesses of the five competing access technologies, namely DSL, HFC, FTTP, satellite, and wireless, the first and most essential parameter to consider is the required speed of the service.

The use of data within the home has been growing at more than 20% per year for many years. Per Oookla, the average landline broadband speed in North America this year is currently running at 203 Megabits per second downstream and 23 Megabits per second upstream. With this speed as a baseline average, today's satellite service can effectively be eliminated as a viable contender except for the niche applications as noted above. Similarly, traditional fixed wireless access or 5G mobile broadband is going to be limited in market penetration and availability. Recently, however, two of the three major wireless operators have been promoting a new 5G-based Fixed Wireless Access service. This solution, along with DSL, hybrid fiber-coax, and FTTP all need to be analyzed for strengths and weaknesses.

Looking first at the 5G-based FWA solution, currently being aggressively marketed by Verizon and T-Mobile, the use of their newly available higher frequency 5G spectrum bands enables a higher bit rate service, up to 182 Megabits per second downstream, to be offered. As these carriers build out their 5G network around the country, the FWA service becomes more broadly available.

Looking now at the three wired solutions, a key factor when evaluating FTTP versus DSL or HFC networks is that the latter two have already been built out to most homes. This means the copper and coax drops have been almost universally deployed in the US and the investment in building these networks has already been recouped. Copper networks were, for the most part, subsidized by the original monopolistic models of the telephone companies, and the coax networks, although privately funded, have taken many years to reach a point of financial viability. In fact, the term EBITDA, commonly but mistakenly used as an indicator of profitability, was first coined by John Malone during the long and expensive buildout of TCI, the largest cable system in the US.

This typically puts FTTP at a competitive disadvantage for new markets because the drop to the consumer's home needs to be installed for every customer, adding a significant cost to the build-out.

Digging a bit deeper, as the original copper and coax-based networks have been upgraded by the operators to provide ever-increasing speeds for consumer broadband, fiber has been deployed by both architectures to reach deeper into residential neighborhoods. This is shown in Figure 3.

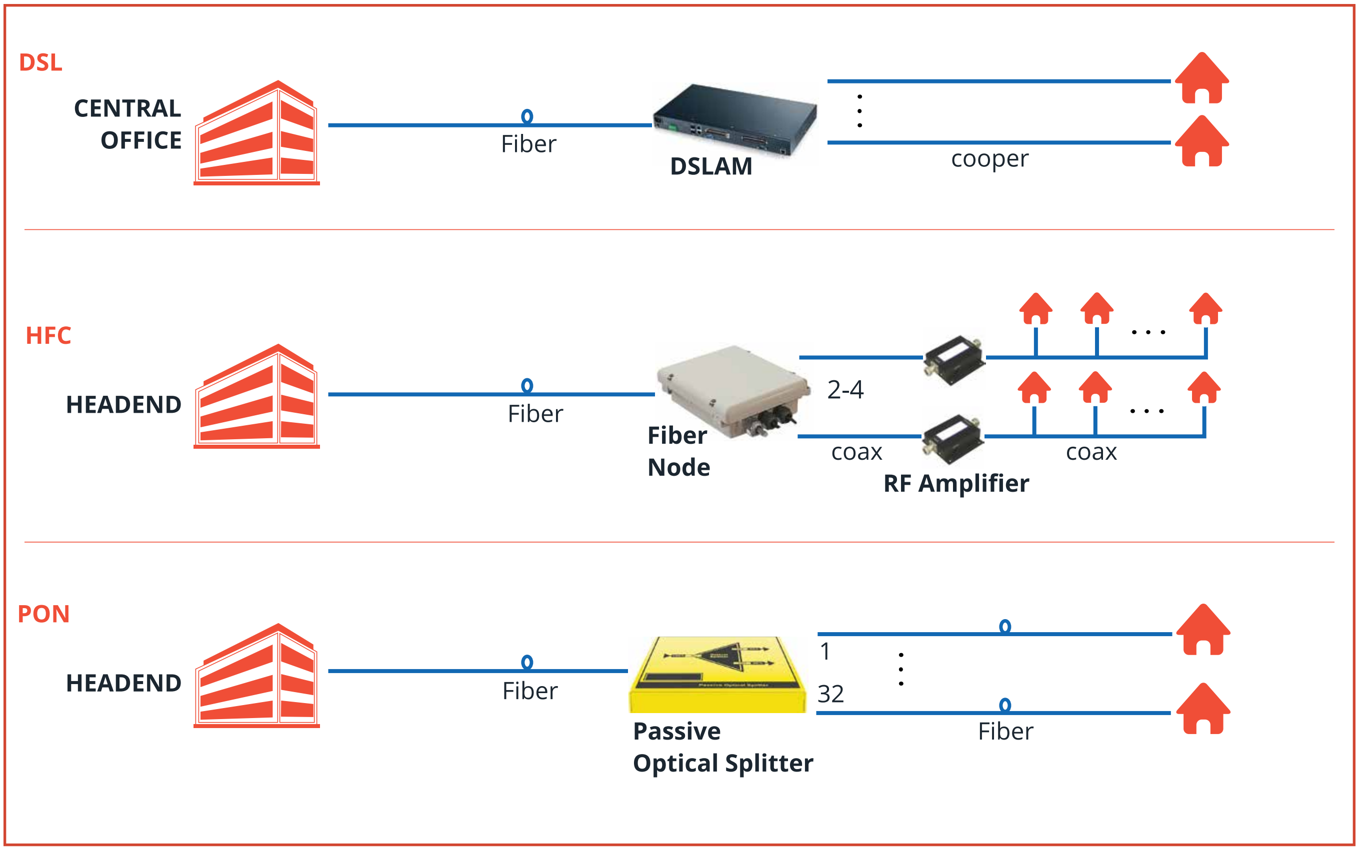


Figure 3. Residential Architectures

So what we end up with, common to all three choices, are fiber-based architectures to the neighborhood, with differing drop connections to the home. The main competitive criteria, in addition to the drop cost, are reliability, operating costs, including maintenance, and evolvability for future bandwidth growth. A key advantage of FTTP versus the other two technologies is that the device used to distribute the fiber to each home is a passive splitter.

For FTTP this means there is no power, no active electronics to be maintained, and no interference from electrical events such as lightning. It is also untappable for improved security. Both coax and twisted-pair architectures use hardened electronics in the neighborhood, which must be powered, maintained, and are subject to interference or intrusion.

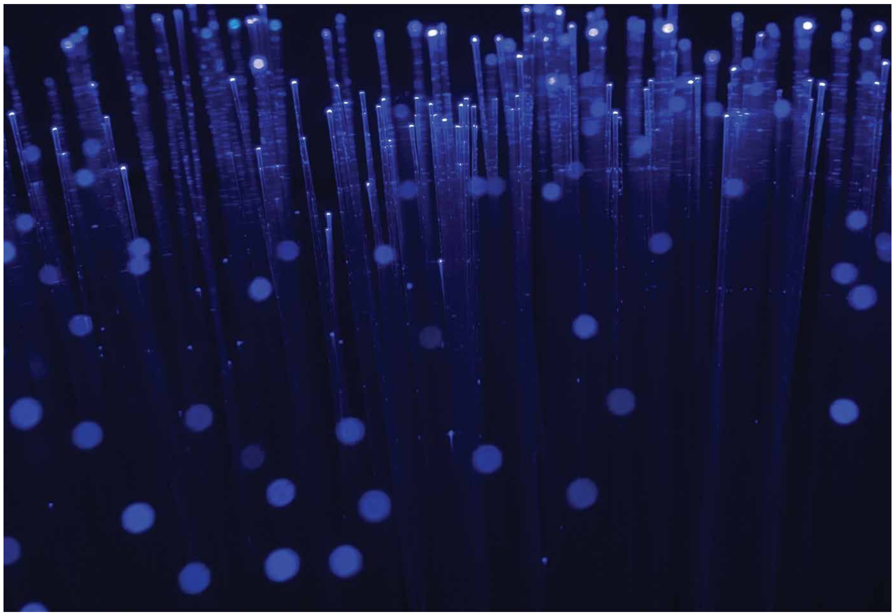
In terms of evolvability, the FTTP architecture can be upgraded to a higher bit rate via changes in the transmitter at the operator's central office location and the optoelectronics in the device at the side of or inside the residence. Coax and twisted pair, in contrast, require significant engineering rework, pushing fiber deeper, and changing out electronics in the neighborhoods.

Finally, twisted pair is reaching the limits of its performance capabilities, while coax and fiber have significantly more bandwidth "runway." These differences are summarized in Figure 4.

Architecture	*Connection to Home*	*Active Electronics*	*B/W Potential*	*Total Member Users Sharing*
DSL	Copper	Yes	100Mb/s	1
HFC	Coax	Yes	10Gb/s	80-150
FTTP	Fiber	No	50Gb/s	32

Figure 4. Residential Comparison

4 USERS NEEDS – CURRENT AND FUTURE



BANDWIDTH REQUIREMENTS: CURRENT AND FUTURE PERSPECTIVES

The primary purpose of broadband networks is to allow users to access Internet-based data services of many types. As we have seen above, different technologies have different capabilities. In this section, we will look at Broadband from the users' point of view – how much bandwidth is needed today and how that will increase in the future.

The biggest current bandwidth need comes from video services. As video quality has improved and streaming has become a popular method of access, a good portion of network bandwidth is consumed by video. Standard definition television requires about 1 megabit per second, with high definition (HD) television requiring typically 5 megabits per second. 4K UHD, becoming increasingly popular, requires 25 megabits per second for a single stream. Gaming devices, such as PlayStation or Xbox have embraced high-quality video as well and can each require 25 megabits per second as well. Smart phones, which typically run over broadband networks at home, are also capable of not only receiving but sending 4K video with the resultant bandwidth need. In addition, smartphones can have many apps automatically downloading in the background, consuming gigabytes of traffic.

With the pandemic came a dramatic rise in the use of video conferencing apps such as Zoom. Depending on video quality, Zoom consumes 540 megabytes to 1.6 gigabytes per hour for a one-on-one session and 810 megabytes to 2.4 gigabytes per hour for group meetings. It requires up to 3 megabits per second bidirectional bandwidth speed. For users with data caps, extensive zoom usage and or multiple users per residence may bump up against those caps for some users. For data speed, the download speed is not an issue, but upload speed may put some stain on low-end DSL and cable offerings.

The average number of IP devices per home is currently more than 20 and growing. While some of these require relatively low bandwidth, more and more are video-based, which can mean several hundred megabits of bandwidth speed to service them collectively.

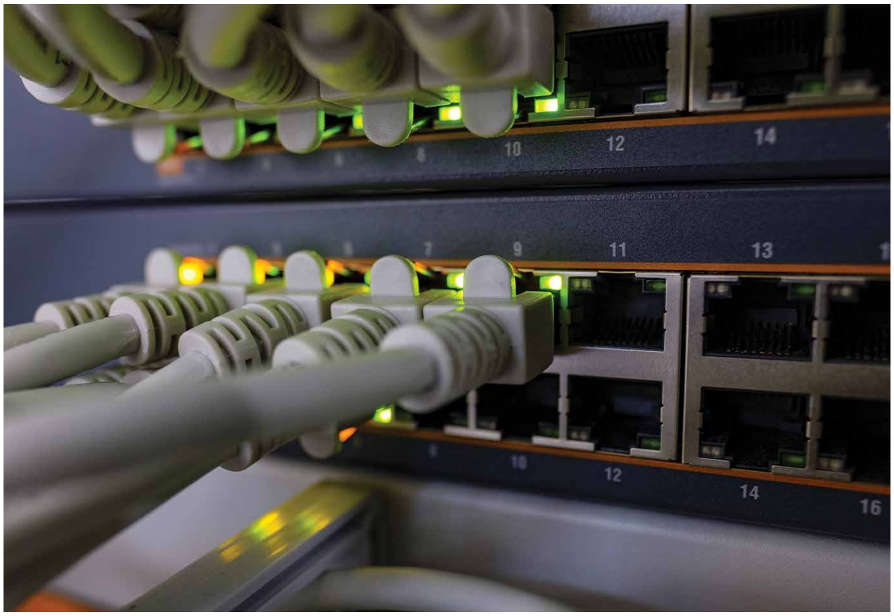
According to a recent Open Vault Broadband Insight report, during the fourth quarter of 2022, the average residential broadband user in the United States consumed 588 GB of data per month, a year-over-year increase of 10%. Only 6% of this data usage was upstream. Average downstream speed was 215 megabits per second and average upstream speed was 25 megabits per second. Gigabit service was purchased by 26% of all subscribers, an increase of over 100% from the previous year.

Looking to the future, there are a number of applications coming which will dramatically increase bandwidth requirements. The two principal new applications which will most likely impact bandwidth needs over the next few years are Augmented Reality and Virtual Reality. Depending on the video quality required, VR can require from 25 MB/s to 400 Mb/s, and AR can require from 100Mb/s to 1Gb/s. These are per-user (headset) numbers. While VR will likely be used only by high-end gamers, AR will have a broader range of applications.

This has been a niche offering to date, with companies like Meta (Facebook), Sony, and Microsoft evangelizing for the past couple of years. On June 5, Apple, after years of rumors, entered the market with the VisionPro headset, riding on over five thousand patents. They have the potential, over the next two or three years, to “make the market” as they did with smartphones, tablets, and smart watches.

An FTTP network with a twenty-plus year planning horizon definitely needs to be ready for the potential success of this technology. If this does indeed happen, the vastly superior upstream capability of fiber will obsolete all other options.

5 FTTP DEPLOYMENTS IN THE UNITED STATES



5.1 OVERVIEW

As of year-end 2022, according to the Fiber Broadband Association, FTTP has passed 68 million homes in the United States, adding 7.9 million passings during the year, and 26.0 million homes have been connected, for an impressive average take rate of 38%. Telcos have built over 80% of these homes passed, with AT&T and Verizon having over 50% of the total build. The full breakout of types of providers is shown in Figure 5.

Historically, twisted-pair copper-based systems (DSL) and fiber hybrid coax (HFC) based systems were deployed by telcos and cable companies respectively to deliver residential broadband service. As consumer demand for speed increased over time, the bandwidth advantage of HFC (big pipe) over copper (little pipe) won out, and the cable companies took the dominant share of residential broadband from the telcos.

To counter this, as well as to enter the lucrative video distribution business, the two major US telcos, AT&T and Verizon, both decided to use an even

Categories	FTTP Provider (%)
Tier 1 Telcos	60%
Tier 2 Telcos	20%
MSOs	8%
Tier 3 Players	12%

Figure 5. **FTTP Provider Categories**

bigger pipe, namely fiber, to compete with the MSOs in video and take back lost share in broadband data. Although FTTP had been introduced in the U.S. on a small scale since the late 1990s, these two telcos drove the first large-scale FTTP deployments.

Verizon, with copper drops that were predominantly aerial and hence more cheaply replaced by fiber, decided to build a true FTTP system called FiOS starting in September 2005. They built a system using BPON for voice and data, with a separate downstream wavelength for broadcast video.

Starting in June 2006, AT&T, with copper connections to the home primarily underground, chose to build a hybrid system (U-verse) taking fiber deep into neighborhoods but using existing copper to carry switched video and data the last 200 feet or so. This means it was not a true FTTP system but rather a hybrid system, which could, however, be converted to true FTTP in the future by replacing the last copper connection with fiber.

The broadcast video requirements of these two systems were solved very differently, and both telcos had to build proprietary systems. Despite being proprietary, the investments by these two majors operators drove the awareness and demand for FTTP systems.

As streaming video technology matured, video could be delivered within the existing data delivery system, rather than handled separately, and a new form of FTTP, GPON emerged as the dominant system deployment choice, including by AT&T and Verizon. This technology has successfully been deployed by many other operators, including smaller telcos, overbuilders, municipal governments, and co-ops. The one major exception to the use of GPON is the MSO segment, whose members use EPON for their limited FTTP builds, for technical reasons.

5.2 VERIZON FIOS

There are three drivers behind Verizon's decision in 2005 to deploy fiber-to-the-premise.

First, their copper plant was aging, requiring a high maintenance budget, and was limited in the data speeds that could be supported using advanced DSL. Second, as noted above, the MSOs were making great improvements to the technical capabilities of its HFC-based data offering, DOCSIS. By this point, Verizon was clearly losing the residential broadband war. Third, the MSOs were enjoying a significant revenue stream from video services over HFC, at the time the jewel in the crown, and making inroads against Verizon's voice offerings with VoIP service on HFC.

Verizon decided to go on the offense, with a superior broadband offering and a competitive video offering, using a purpose-built fiber-to-the-premise system known as FiOS, which they launched in 2005 in Keller, Texas.

As the pioneer for a large-scale FTTP deployment, Verizon faced two principal challenges. First, they had to come up with the learning curve on the deployment and connections to the home of the fiber itself. Second, they had to develop a custom solution for delivering a professional quality video offering over fiber.

The first challenge, field deployment of the fiber itself, took quite some time and effort to solve. The fact that most of the existing copper plant was aerial (both distribution and drop to the home) was essential to hitting their business case goals since the underground plant was 2 to 3 times more expensive to deploy.

A principle technical and cost issue was the splitting and termination of the fiber itself. At the time, the best technical solution was called fusion splicing, which required a skilled technician and mild weather (no rain or excessive wind). The initial install times were greater than four hours on average per home, meaning two homes per shift could not be done by their unionized technicians without paying overtime. In addition, in many cases, the environment, particularly multi-dwelling units, was not deemed safe for a single technician to enter, so they worked in pairs, with a third technician needed to stay with the truck to avoid vandalism.

The install time interval could be considerably speeded up with the use of pre-connectorized fiber, but the optical loss introduced by the connector made this a nonstarter for the carriage of video and for unterminated split links. The development of the hardened angled physical contact (APC) connector solved this problem. In conjunction with ONT devices at the residence interface with fiber trays enabling excess fiber to be coiled without exceeding the bend ratio limits, this enabled the technicians to carry a small number of pre-connectorized fiber cable lengths in their truck, significantly improving install time, the single biggest cost factor in the early deployments.

Companies like Corning were critical of the advances needed to get the costs down. Bell Aliant from eastern Canada, with a strong recommendation from Scientific-Atlanta to deploy FTTP, was another early pioneer, ultimately passing over two million homes, and worked closely with Verizon on best practices to drive install costs down.

The second major technical issue for Verizon was the deployment of cable TV-style video on their PON. A separate wavelength at 1550 nm was used to carry QAM-modulated video downstream, similar to HFC networks. A key cost leverage point for Verizon was the use of existing copper outside plant enclosures to house the fiber-to-the-premise splitters. To do this, however, and carry the video signals, an optical power budget far exceeding current HFC practice was required. A single-sourced product, a super high-power optical amplifier known as a YEDFA (Ytterbium-Erbium Distribution Fiber Amplifier), was provided by Scientific Atlanta. Without this product, video services on the FiOS system would not have been economically possible.

Verizon's network equipment was initially built by Motorola for FiOS triple-play services. Many building blocks common to HFC were used for the headends and hubs, but a custom-designed set-top was required. Scientific-Atlanta provided the network equipment for the last ten cities using an IP rather than an RF design.

FiOS was, and still is, well received in the marketplace, with Verizon typically taking 25 to 30% of the market share.

After some years of operation, Verizon refocused their triple-play services back to the northeast corner of the US, as they put more resources on their wireless offerings. They sold off both their FiOS and copper DSL lines outside of their core region to other telephone companies such as Frontier Communications.

As of 1Q23, Verizon had over 6.8 million FiOS residential connections, with 3.2 million taking video, available in ten states in the northeastern US. Verizon remains the second largest provider of FTTP in the country and continues to market and build out FiOS services.

5.3 AT&T U-VERSE/GPON

In the mid-2000s, AT&T was facing the same issues as Verizon regarding competition from the MSOs. Unlike Verizon, with a copper plant that was old and primarily aerial, AT&T had newer copper, which was in many cases underground, making a massive rollout of fiber to the home cost prohibitive. Instead, AT&T chose to run fiber deep into the neighborhoods and continue to use copper for the last short segment to the home. This system architecture began as Project LightSpeed and was launched as U-verse. DSL speeds over copper degrade as distance increases. By shrinking this distance considerably, the DSL speeds could be increased accordingly. An aggressive target was set of 25 Mb/s per home, which was significantly more than the MSOs were delivering at the time, typically 5 Mb/s.

With this approach, the threat of broadband subscribers being lost to the MSOs was mitigated, and the network upgrade cost was significantly lower than a full fiber-to-the-premise deployment. The big issue, however, with this design became one of providing professional quality video which needed to share the 25 Mb/s home budget. To address this, AT&T had no choice but to move to a switched video solution, quite radical at the time, and rely on a newly invented superior video compression scheme known as MPEG-4 to provide video service, including high-definition video.

Alcatel provided the DSL equipment (the highest cost), and Scientific Atlanta provided the custom video network solution, building headends in Kansas City and Atlanta, and Video Serving Offices (hubs) in 54 cities throughout AT&T's territory.

Service was launched in June 2006 in San Antonio, Texas. Improvements in the DSL electronics over time allowed AT&T to increase the bandwidth to 70 Mb/s per home.

U-verse ultimately passed over 30 million homes in 22 states. By the end of 2014, U-verse had 12.2 million data subscribers, 5.9 million video subscribers, and 4.8 million voice subscribers.

At this point, AT&T announced their intent to acquire DIRECTV for $48 billion, which became over time their principal video offering, and U-verse video began to decline in focus and then subscribers. As part of the DIRECTV acquisition, AT&T agreed, among other things, with the FCC to provide broadband Internet access capability via fiber to the home to 12.5 million subscribers.

This put AT&T in the fiber-to-the-premise business in a big way. The FCC commitment was met in 2020. As of 1Q23, AT&T has 7.5 million fiber-to-the-home subscribers as well as 6.2 million U-verse data subscribers and 220,000 DSL subscribers.

Their stated plan is to have 30 million FTTP homes passed by the end of 2025, putting fiber to the premise firmly in the top strategic priorities of AT&T.

5.4 OTHER TELCOS

Tier 2 telcos, some of whom purchased Verizon FiOS systems in cities like Fort Wayne IN, Portland OR, and Buffalo NY are collectively passing about seven million homes. They are growing their footprints aggressively and have collectively announced public plans to pass another 10 million homes with FTTP over the next decade.

5.5 OVER-BUILDERS

Over-builders are defined here as private firms that see an opportunity to compete with existing telephone and cable companies to build a new network. A number of these companies launched in the mid-2000s, primarily using Hybrid Fiber Coax as their network of choice. Companies like Knology, WideOpenWest, and RCN built new networks and competed primarily by doing a better job with customer service, local content, and to some extent, price.

Reynoldsburg is one of the cities overbuilt with HFC by WideOpenWest. About 65% of the city's footprint is covered by this network. In 2022, Wide Open West sold its Ohio properties, including Reynoldsburg, to another over-builder, Atlantic Broadband, who is in turn owned by Cogeco, a large Canadian MSO based out of Montreal. In keeping with its wider footprint, Atlantic Broadband recently changed its name to Breezeline.

As data rates increased, fiber to the premise more recently became the preferred network for over-builders.

The most aggressive and interesting of these players is Google Fiber. Their efforts began as one of the parent company Alphabet's "moonshots" with audacious goals and no expectation of near-term financial viability. Their intent was to stimulate usage of high bandwidth applications by pushing the envelope on available broadband speeds, particularly upstream.

Kansas City was the first deployment, having been selected among 1,100 applicants to be the first location. The focus was put on cities with tech-savvy young urban professionals as target customers. By 2015 service was expanded to 10 cities. The estimated cost of completely wiring these cities was over $1 billion each. Google paused the program in 2016 and dropped its internal video offering in favor of a bundled streaming option. In San Antonio, Texas, Google Fiber announced its intent to build 4000 linear miles of fiber, but as of May 2019 had only built about 600 miles.

A number of measures were taken to curb costs, including "nano trenching" at a very shallow distance and high-power optics to drive more users per split and/or further reach from the headend. They also pioneered the process of "fiberhoods" whereby a threshold percentage of users committed to signing up for service prior to the construction being started. They have had a number of construction-related issues and have shut down service in some cities such as Louisville, Kentucky, abandoning the nano trenching process in favor of a deeper micro trenching process in other cities.

Overall, the service is available in eighteen cities with 2 Gb/s downstream and 1 Gb/s upstream service at $100 a month, including free installation and the Wi-Fi6 router.

Google is also offering a Fixed Wireless Access service, called WebPass in eight cities.

5.6 MSOs

The Multiple System Operators (MSOs) are the cable companies that use Hybrid Fiber Coax as their network of choice. Their standardized data offering on this network, DOCSIS, has been phenomenally successful, undergoing continual evolution and enhancement for many years, and allowing them to build and maintain a dominant share of the residential Broadband data market. As this network has evolved, the fiber part of HFC has been pushing deeper and deeper into the neighborhoods.

Although there has been some consideration for taking the final step and pushing fiber all the way to the home, it appears the MSOs are planning further enhancements to DOCSIS to allow a 10 Gb/s service to be offered in the future, without having to change the drop to the home from coax to fiber.

There are two notable exceptions to this bet on HFC as a continued network of choice. The first case for Fiber to the Premise is driven by major property developers, who offer to partner on video services for their tenants but require an all-fiber infrastructure as a marketing tool for their properties. All of the big MSOs have developed programs to respond to these opportunities, building on their expertise in all-fiber-based deployments for business customers.

The second case involves one of the newer large MSOs, Altice, which is the fourth largest operator in the United States with 4.9 million subscribers.

Altice has its roots in the Netherlands and entered the US market in 2010, acquiring two existing MSOs, Suddenlink, and Cablevision.

The Cablevision property covers the northeastern US, directly competing with Verizon FiOS. In 2016, Altice launched a program to convert its network to a fiber to the premise system capable of providing 10 Gb/s service, focusing on the areas of direct competition with FiOS. As of YE2022, Altice has built out FTTP passing 2.2 million locations.

Of note here is that Altice is offering a full-triple play service including “cable TV-style” video, utilizing technology from the parent company in Europe. This gives them, similar to Verizon and AT&T, access to a higher revenue stream per subscriber than most other fiber-to-the-premise players.

Overall, the MSO operators have about 5.5 million locations passed or 8% of the total fiber to the premise deployment.

5.7 MUNICIPALITIES

In the early 2000s, many municipal governments undertook Fiber to the Premise projects to enhance the quality of life for their citizens. In an often-cited analysis done by Professor Christopher Yoo at Penn Law School’s Center for Technology, Innovation, and Competition, 88 municipal fiber projects were examined, most of which were small rural communities. Costs per home passed, not including customer drop fiber, ranged from $765 to $5,549, with a median cost of $2,215. Twenty of these systems reported their financials separately, and the study did an NPV analysis of each of these builds over the period from 2010 to 2014.

What was found was not encouraging. Eleven were cash-flow negative, seven would require more than 60 years to break even, and only two had reasonable financials. One of these systems was in Bristol, TN. Scientific Atlanta provided Bristol with a video headend, high-powered YEDFA optical amplifiers, and a custom-designed video ONT to enable them to capture a higher revenue per subscriber than most other fiber to the premise systems.

Several factors were at play in the poor financial performance noted in Professor Yoo’s study. First, the fiber builds themselves were undergoing a steep learning curve on cost reduction. Second, video services, viewed as an essential offering at the time, required a complex implementation, with smaller suppliers, higher network costs, and higher content costs. Third, the business operations cost of customer service, maintenance, marketing, etc., was new for many municipal governments.

Over time, however, for the surviving operators, costs were lowered, and the nature of the business changed, with higher bit rates, especially upstream, favoring fiber to the premise, and video service becoming less important in the overall mix.

By 2018, Kagan Associates identified 218 active municipal providers, with 174 of them overbuilding existing operators and 44 buildings in new unserved areas. Ten percent of these projects were a public-private partnership, and only about one-third offered some type of video service in the mix. Only five percent included a smart grid offering.

Looking at some examples of municipal deployments: Cedar Springs, in northwest Iowa, has 42,000 residents living in 16,000 homes. Cedar Springs municipal government began in the late 1990s with pre-DOCSIS Hybrid Fiber Coax and then upgraded to DOCSIS. In 2006 they began experimenting with the BPON, then being deployed by Verizon. In 2010, they launched a three-year program to replace their HFC network with GPON, spending about $20 million, Their GPON supplier, Motorola, exited the business and put their products on an end-of-life cycle, so a switch had to be made to Calix as their principal supplier, with significant disruption. in 2012 they provided a Fixed Wireless Access service to some subscribers and went through one product upgrade cycle but are now in the process of shutting it down in favor of fiber to the home.

In 2020 they began a three-year project to upgrade to a 10Gb/s XGS-PON. Partway through the upgrade, they changed vendors from Calix to Ciena, which had a superior XGS-PON offering. This upgrade involves changing out the OLT equipment and upgrading the routers at the headend, and changing out the ONT at customers' homes, but the fiber network deployment is untouched. PON systems run in parallel during the transition.

Cedar Springs has an amazing 90% market share for broadband data. They offer video service as well, which requires a lot of ongoing effort to maintain. They were selected by PC Magazine as Fastest ISP in the Nation in 2020 and the best Gaming ISP in the Nation in 2021.

A 10 Gb/s service is being offered for $107 per month with no install fees and no contract.

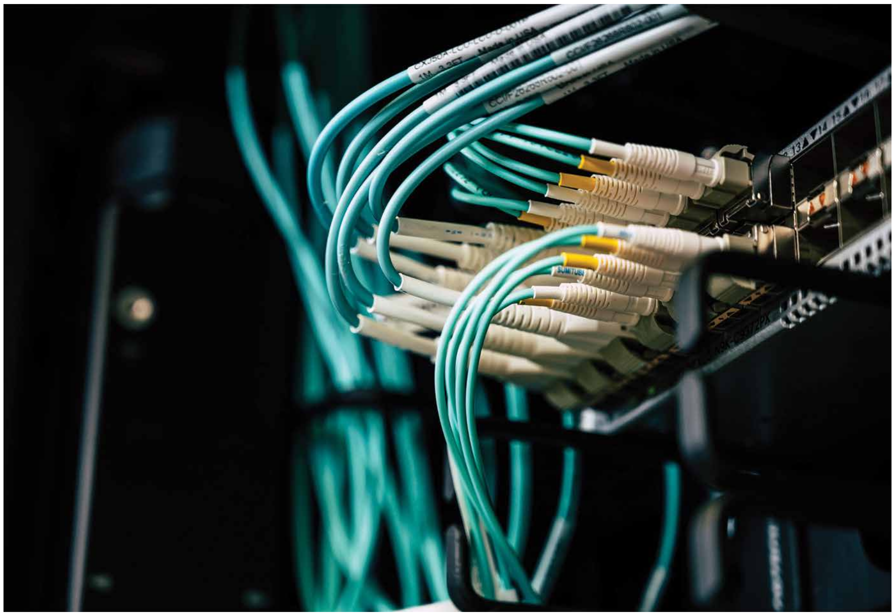
In Medina County, OH, a public-private partnership-based FTTP buildout is underway to provide service to 50,000 households over the next three to five years. The project is expected to cost $50M and is being financed by Lit Broadband and Peak Communications, the two private partners. The first phase, costing $8M, was built in 2021. A mix of aerial and underground construction has been built. The “fiberhood” concert, pioneered by Google Fiber, has been used to determine which neighborhoods were built first. The network is planned to be (digital) Open Access based. Video Services will be exclusively streaming offerings. Another small but interesting deployment is in Ammon, Idaho. They began building their first neighborhood of five hundred homes in March 2019. Residents in each neighborhood are able to join a Local Improvement District (LID), with the costs to build the network shared by those who opt-in. They can pay their share upfront or over a twenty-year period. The network is Open Access, with four companies currently offering internet access.

5.8 RURAL ELECTRIC CO-OPS

Electric co-ops represent nonprofit community-owned entities that provide power for 42 million mostly rural Americans. As of 2018, per Kagan Associates, 163 co-ops are providing one gigabit per second Fiber to the Premise service, out of the 900+ co-ops in the country. Their model is heavily dependent on government subsidies, for the most part. A density of at least eight customers per mile is considered the benchmark for economic viability. The advantages of these co-ops are outside plant experience, including trenching and aerial construction, as well as billing and customer service capability.

Electric co-ops are not on the leading edge of innovation but are providing an increasingly essential service to their large consumer base.

6 CURRENT BROADBAND MARKET SHARE - U.S.



BROADBAND MARKET DYNAMICS AND MAJOR PLAYERS IN THE U.S.

In the first quarter of 2023, per the Leichtman Research Group, the major broadband suppliers in the U.S., representing 96% of the market, added a net 960,000 new subscribers. This drove the total market base to 112 million subscribers.

The MSOs, with 76 million subscribers, have over twice as many subscribers as the telcos, with 31 million subscribers. Almost all net growth came from Fixed Wireless Access-based providers, now totaling 5 million subscribers.

While the MSOs were essentially flat, the telcos added 500,000 fiber-based subs offset by equal losses in their DSL base, as this technology effectively reaches the end of life. This puts the telco Broadband base at 22.5 million fiber-based and 8.5 million DSL-based subscribers.

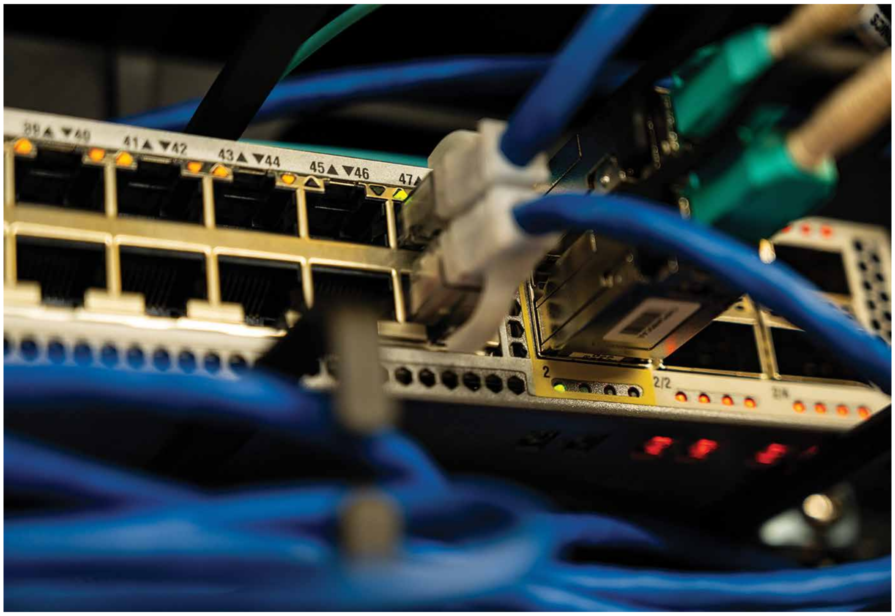
Looking back over the past year the same picture emerges with the MSOs effectively flat, the telcos replacing DSL subs with fiber subs, and FWA providing all of the net growth of 3.4 million subscribers.

Comcast and Charter are by far the biggest MSOs with 82% of the total MSO base. For the telcos, AT&T has roughly half of the telco Broadband base, with Verizon at 24% and five second-tier telcos serving the rest. For the fixed wireless access providers, T-Mobile has 60% of the base and Verizon has the other 40% of the base. Market share by technology type is shown in Figure 6.

Service Type	*Connections (millions)*
FTTP	24M
DSL	8M
HFC	76M
Satellite/ FWA	6M
Total	**114M**

Figure 6. Residential Broadband Connections – US

7 EXPECTED EVOLUTION OF BROADBAND SERVICE ALTERNATIVES



7.1 INTRODUCTION

Over the last 18 months, three things happened to upset the equilibrium of the Broadband Services market. These events have set up an expected evolution path over the next few years to continue to provide increasing speeds to subscribers.

First, the FTTP providers have rapidly shifted from GPON to XGS-PON, enabling more bandwidth to be offered than that of the MSOs, significantly shifting the competitive advantage from the MSOs to the FTTP providers.

Second, to counter this, the MSOs have accelerated their program to evolve their HFC-based networks to a new data standard, DOCSIS 4.0, to match the FTTP XGS-PON 10GB/s capacity, at least in the downstream.

Third, Fixed Wireless Access, which had been a very niche service, was embraced by two of the three big wireless carriers (T-Mobile and Verizon) with a higher bandwidth offering by leveraging the huge investments in their 5G networks.

Let us look at each of these in turn.

7.2 FTTP BANDWIDTH EVOLUTION

The evolution of FTTP systems to higher bandwidth is a comparatively easy process for two main reasons:

First, the fiber itself is capable of transmitting multiple wavelengths (think colors) at the same time. The standards process has taken advantage of this property by defining unique wavelengths for each type of PON system so that all can be carried at the same time on the same fiber. This means that existing networks can have higher speed optics added selectively, without disrupting existing service.

The second reason for the ease of upgrade is economical. Since the bulk of the cost in FTTP builds is in the outside plant construction and connection of fiber, the higher-end optical equipment cost, even at a significant premium, has a minimal impact on the overall cost.

This is why, although most deployed FTTP networks today are based on GPON, the competitive offer has now shifted to XGS-PON for both existing and new FTTP networks.

Since XGS-PON provides 10 Gigabits per second capacity both downstream and upstream, shared by up to 32 users, a 2 Gigabit per second symmetrical or even 5 Gigabit per second symmetrical service can be offered, and these speeds are being rolled out all across the country today.

We will disregard the NG-PON2 technology, which provides up to 4×10 or 40 Gigabits per second, for purposes of this report, since only Verizon is currently deploying it and the technology is much more complex.

The next step for PON evolution in most FTTP networks, therefore, will be a 25 Gigabits per second PON. This requires a new OLT in the headend and a new ONT in the subscriber's location. This technology can be added to existing PON networks selectively using unique wavelengths, as outlined above.

The technical challenge with this higher speed PON is not actually the OLT, which is a fairly simple upgrade, but rather the ONT at the subscribers' premise, since handling the "many to one" transmission slotting is currently quite difficult at this very high speed. Since there is one ONT per subscriber versus one OLT for up to 32 subscribers, the ONT cost dominates the increased cost of 25 Gigabits per second PON.

A number of smaller networks are up and running at this speed, but it is expected that the ONT cost will limit mass deployment for some time. A similar upgrade path to 50 Gigabits per second PON is also on the horizon, paced two or three years further out.

Over the long term then, assuming the need for this speed by subscribers actually materializes, fiber-based networks will become the only viable network offering.

7.3 DOCSIS 4.0

The MSOs use a formal specification and certification process managed by a jointly owned entity, CableLabs. This allows vendor interoperability and lowers overall costs. The next evolution of the currently deployed DOCSIS 3.1 standard is DOCSIS 4.0, which has been under development for several years now. This specification will enable a multi-gig downstream service to be offered to individual subscribers but upstream will be more limited.

Another major program has taken a higher priority in the standardization, certification, and deployment cycle. This program is Distributed Access Architecture (DAA). As a first step, virtualization of the network side of the Broadband system is being implemented, a technique being utilized by all types of network operators worldwide. Virtualization lowers network costs while increasing deployment flexibility and system upgrade velocity.

In conjunction with this, Distributed Access Architecture pushes the DOCSIS signaling out to the fiber node. This enables lower user latency and increases the bandwidth available to users by allowing more efficient modulation techniques. 5G wireless networks are taking a similar path, with container-based virtualization of the core and Multi-access Edge Computing (MEC) processing pushed to the edge.

The DAA program, pioneered by large MSOs such as Cox Communications and Comcast, has turned out to be quite difficult from an operations and maintenance perspective and is only recently rolling out in volume.

For DOCSIS 4.0 itself, which requires DAA, there are two competing methods of implementation that have been standardized. The first method changes the system from the currently deployed simplex mode to a full duplex. This version is being championed by Comcast, the largest MSO. The second method increases the size of the coax pipe from 1.2 to 1.8 gigahertz. This version is being championed by Charter, the second-largest MSO. Each of these methods requires new silicon for volume deployment and extensive upgrades, including environmentally hardened electronics in the field. (In contrast, Fiber to the Premise has NO electronics in the field).

In December 2022, Charter Communications laid out its DOCSIS 4.0 vision for a $5.5 billion network expansion and upgrade, taking a three-tiered approach to increased bandwidth availability.

Beginning this year, 15% of their footprint will be upgraded to two gigabits per second downstream and one gigabit per second upstream capability.

Beginning early in 2024, a further 50% of its footprint will be upgraded to five gigabits per second downstream and one gigabit per second upstream.

Beginning later in 2024, the remaining 35% of their footprint will be upgraded to 10 gigabits per second downstream and one gigabit per second upstream.

Blended cost is expected to be $100 per premise passed, or $5.5 billion total for their 55 million premise footprint. The program is planned for completion by the end of 2025.

Also in December last year, Comcast, which is using a more complex version of DOCSIS 4.0, announced it would begin deploying systems this year and plans to upgrade 50 million of their 61 million homes passed by the end of 2025. The expected upgrade cost will be $10 billion or $200 per home passed. Cable ONE, a much smaller operator, just announced their expected cost for the Charter style DOCSIS 4.0 upgrade to be $200 per home passed.

Both versions of DOCSIS 4.0 will support up to 10 Gigabits per second downstream. The Comcast system will support 6 to 8 Gigabits per second upstream, and the Charter system will support one gigabit per second upstream.

7.4 5G-BASED FIXED WIRELESS ACCESS

As described above, 5G-based Fixed Wireless Access (FWA) has taken the Broadband market by storm, driven by large marketing campaigns from T-Mobile and Verizon, and a sweet spot of low price, quick installation, and sufficient bandwidth for many customers today, especially where the principal competition is DSL. The question then becomes where this technology will play out as a subscriber's need for speed increases over time.

The bandwidth supported by an FWA system is a function of the frequency of the wireless transmission. Traditional FWA systems, using frequencies similar to pre-5G wireless networks, only support speeds up to 50 Megabits per second or so, and have been a niche product.

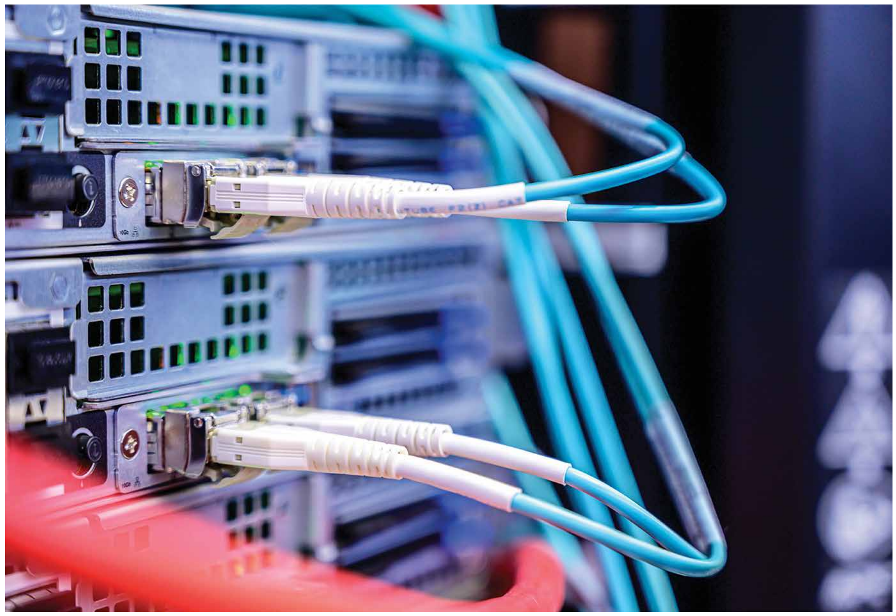
5G networks however are being built out with higher frequency antennas and are being leveraged by T-Mobile and Verizon to deliver up to 180 Megabits per second, depending on traffic levels and distance from the antenna.

AT&T is not deploying 5G-based FWA technologies, at least for consumer use at consumer prices, arguing that the wireless spectrum can be utilized by mobile customers at much relatively higher price points. As traffic grows on the Verizon and T-Mobile networks, it is not clear that FWA will continue to be able to grow when competing with mobile customers.

There is also a higher set of 5G frequencies, called mmWave, that could produce much higher FWA speeds. These frequencies have a much more limited coverage range, however, and will not likely be broadly deployed across the entire wireless footprint.

It is expected that over time FWA-based services will reach capacity constraints, and will not be able to compete with fiber, but for current subscriber needs, 5G-based FWA has definitely found a sizable market.

8 FTTP ACTIVITY IN OHIO



MAJOR PLAYERS AND SMALLER NETWORKS BOTH DRIVE GROWTH

There is a flurry of FTTP activity across the state of Ohio, including the entire spectrum from very small build-outs to multi-city multi-year announcements from some of the bigger players.

Brightspeed, whose parent company Apollo Global Management acquired 7 million copper passings from Lumen over 20 states, announced plans last year to build 170,000 FTTP passings across 12 Ohio cities in 2023. They also announced plans to build 210,000 more passings over the next few years for a total of 380,000 new FTTP passings in Ohio.

In March 2023, Horizon, the incumbent local exchange carrier in Chillicothe, Ohio, announced plans to buildout FTTP to 117,000 passings in 13 Ohio communities.

Altafiber, (formerly Cincinnati Bell) has announced a $1.5 billion network investment plan covering parts of Ohio, Kentucky, and Indiana. Announcements in Ohio include 52,000 passings in Warren County and 58,000 passings in Butler County. On June 26 of this year, Altafiber was selected to build a 10Gb/s XGS-PON network for the city of Dublin, Ohio.

AT&T has announced upgrades to their existing GPON networks in five Ohio cities, namely Cleveland, Columbus, Dayton, Toledo, and Youngstown, to 10 Gigabit XGS-PON capability. Customers in these cities will be offered two-gig and five-gig symmetrical services. It should be noted that AT&T does not typically cover the entire city footprint with their fiber builds, offering slower-speed DSL service to the non-fiber footprint.

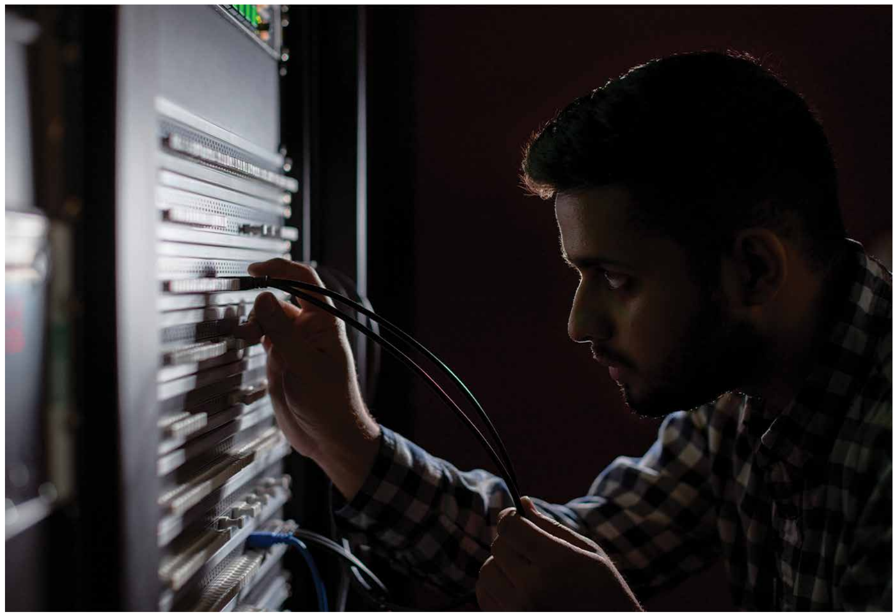
Some examples of smaller scale builds:

- NKTelco, serving West Central Ohio, is expanding, and upgrading its system in Marysville and surrounding areas. This will include coalescence with the 33 Smart Mobility Corridor in The Beta District.

- Metronet, an Indiana-based fiber provider is currently building a system in Findlay, Ohio.

- Even at a very small scale, NCWCOM is building a state government-funded FTTP system for 324 addresses in Huron County.

9 CURRENT BROADBAND SUPPLIERS IN REYNOLDSBURG



REYNOLDSBURG BROADBAND LANDSCAPE

Reynoldsburg has Broadband Services, defined by the FCC as 25 Megabits per second downstream and 3 Megabits per second upstream, available to virtually all of its residents.

The incumbent cable service provider is Spectrum, which has upgraded its broadband data system to DOCSIS 3.1, enabling downstream speeds of up to one Gigabit per second and upstream speeds of up to 35 megabits per second.

There is a second (overbuilt) cable system covering 65 to 75% of the city provided by Breezeline (formerly WideOpenWest.) This system has equivalent speeds to Spectrum.

The major incumbent DSL provider is AT&T, which covers 92% of the city. Part of their network, covering only about 3% of the city, has been upgraded to fiber. Fiber service is likely available up to 1 Gigabit per second symmetrical. AT&T does not make local plans publicly available.

BrightSpeed, after acquiring a small number of copper phone lines, is offering low-end DSL to about 8% of the city.

T-Mobile and Verizon are covering the city with their 5G FWA services. Individual coverage cannot be guaranteed, and speed will vary dynamically from 30 Megabits per second to 180 Megabits per second downstream and 6 Megabits per second to 23 Megabits per second upstream.

There are also two pre-5G FWA providers, Point Broadband and Bresco Broadband, each with about 50% coverage and speeds of up to 50 Megabits per second downstream. A third FWA provider, Starry, recently went bankrupt and withdrew from the market.

The two nationally ubiquitous satellite providers, ViaSat and Hughes offer service up to 100 Megabits per second and 25 Megabits per second downstream respectively, with extremely limited upstream speeds.

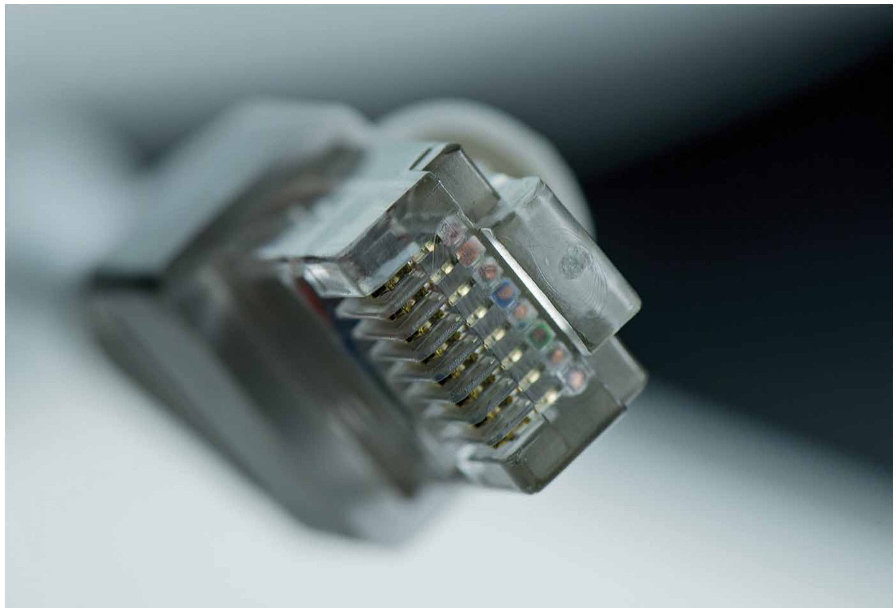
The full suite of broadband suppliers is summarized in Figure 7.

Reynoldsburg residents have an average download speed of 120 Megabits per second (90% of the US average) and an upload speed average of 21 Megabits per second (46% of the US average.)

Provider	Type	↓Speed (Mb/s)	↑Speed (Mb/s)	Coverage
Spectrum	Cable	1000	35	100%
Breezeline	Cable	1000	50	65-75%
AT&T	DSL	50	20	92%
AT&T Fiber	FTTP	1000	1000	3%
BrightSpeed	DSL	20	5	8%
T-Mobile	5G FWA	30-192	6-23	100%
Verizon	5G FWA	30-192	6-23	100%
Point Broadband	FWA	50	50	50%
Bresco Broadband	FWA	50	50	60%
ViaSat	Satellite	100	5	100%
Hughes	Satellite	25	3	100%

Figure 7. Residential Broadband Providers in Reynoldsburg, Ohio

10 RECOMMENDED FTTP ARCHITECTURE AND ASSUMPTIONS



OPTIMAL FTTP ARCHITECTURE AND ASSUMPTIONS

As we saw in Section 2 above, an FTTP system uses shared fiber to allow users to access a range of Broadband Services. A simplified diagram of a fiber the premise system is shown in Figure 8.

A number of parameters need to be established to build the optimal system for Reynoldsburg as follows:

DATA CENTER LOCATION

Given the geographic reach and city population, a single data center location will be sufficient to serve the entire city. Ideally, this location should have or be built for redundant power feeds, battery, and generator back up, and diverse fiber entry/exit routes. Note that the cost of securing a suitable location for a data center is not included in the cost estimates given below.

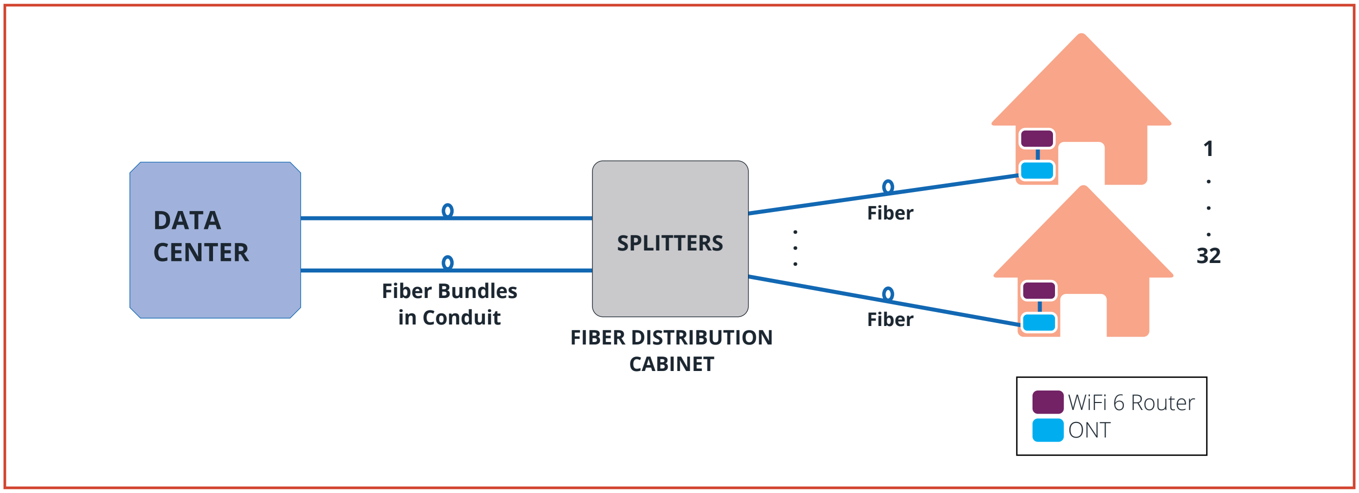


Figure 8. XGS-PON Architecture

NETWORK SPEED

The majority of existing FTTP systems use GPON technology today which provides 2.4 Gb per second capacity downstream and 1.2 Gb per second capacity upstream and can hence support a one gigabit per second provisioned service.

For new builds however, the preferred technology has rapidly shifted to XGS-PON, which provides 10 Gb per second downstream and upstream and can support 2 Gb per second and even 5 Gb per second services.

Since the overall system cost increase will typically be less than 5%, it is recommended to get out in front of bandwidth growth needs by building an XGS-PON system.

DATA CENTER EQUIPMENT

Equipment required at the Data Center would consist of OLT racks, switches and routers, a fiber management system, Operational Support Systems (OSS) and Business Support Systems (BSS) equipment.

This is shown schematically in Figure 9. For a system serving Reynoldsburg, less than five racks of equipment plus a fiber cross-connect rack would likely be required.

The number of fibers entering the building would be roughly 600. A workstation space would also be required.

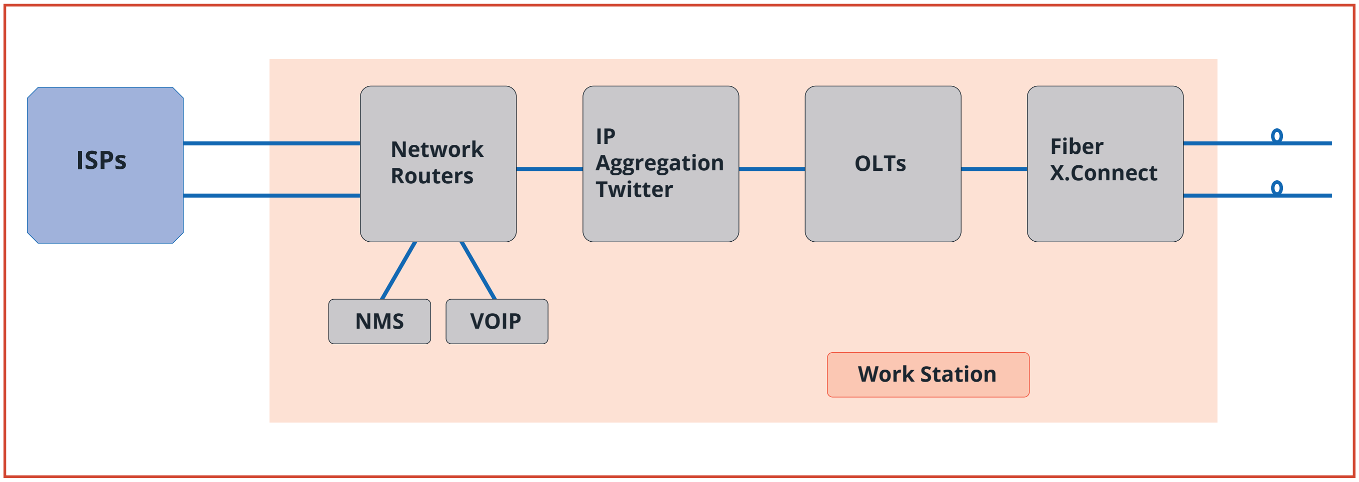


Figure 9. Simplified Data Center Equipment Modules

SERVICES

Although broadband data is typically the primary service, triple-play offerings are sometimes provided, adding voice and video to the mix. Given that the Fiber to the Premise build is a greenfield effort, customers will be migrating over from competitive providers, and they will in many cases be expecting triple-play services.

Voice capability is quite easily added to the service offering by adding a VoIP gateway at the Data Center. The Wi-Fi6 router at the premise comes equipped with VoIP connections. A number of companies are available with which to partner in operating this service.

For video services, the situation is more complex. Traditional cable-based video services, also known as "linear video," require a significant investment in designing and building a video headend to provide this capability, and it is not recommended to do this.

The public is rapidly migrating to a streamed video model. It is recommended that this capability be offered for video services by bundling one or more streaming services such a Sling TV, YouTube TV, or Hulu as part of the service offering. No hardware in the Data Center will be required for this capability.

FIBER ROUTING PLAN

If a more accurate cost model is desired, prior to a decision on viability, a fiber modeling process can optionally be conducted. This uses a set of desktop modeling tools, in conjunction with city GIS data, to get a more accurate assessment of how much conduit construction, fibers, and FDC placement would be needed. This process typically costs $50,000 to $70,000 and takes up to two months to perform.

OVERHEAD VS UNDERGROUND CONSTRUCTION

Since this data has not been provided, for costing purposes an even split of aerial and underground construction will be assumed.

OUTSIDE PLANT (OSP) CONSTRUCTION

For the underground portion of the build, although some builds have been done recently with a process called micro-trenching, this is not a preferred method for long-term viability and is not recommended. The horizontal boring method, which takes longer but minimizes disruption to the landscape, and buries the conduit deeper, is recommended as the conduit construction method.

FIBER DISTRIBUTION CABINET AND SPLITTERS

The industry standard split ratio for XGS-PONs is 1 x 32, meaning up to 32 homes share the 10 Gigabits per second bandwidth available on the system in each direction. For the underground portion, Fiber Distribution Cabinets (FDC) will need to be placed somewhere in each neighborhood to house the splitters serving those homes. This placement will be finalized during the fiber layout design process but will typically service 200 to 300 homes and allow space for extra splitters to enable future selective capacity increase by reducing the split ratio to 1 x 16.

Unlike Hybrid Fiber Coax or DSL builds, no power will be needed at these sites. The distribution fiber feeding each neighborhood will be over-provisioned to accommodate for this type of growth or other uses such as cellular backhaul, which may represent a significant future opportunity as all three wireless carriers upgrade to 5G service.

DROP FIBER

From the splitters in the FDC, individual fibers will be run to each premise and connected to an Optical Network Unit (ONU). It is recommended that fibers be pre-connectorized and available in a small number of lengths to optimize the installation process. For small multi-family units, duplexes, townhomes, etc., the process is essentially the same. For large apartment complexes, the splitters are contained in cabinets on the outside of the apartments, (see Figure 10), with appropriate fiber counts to serve them. Fibers are then distributed within the complex to ONUs within each apartment.

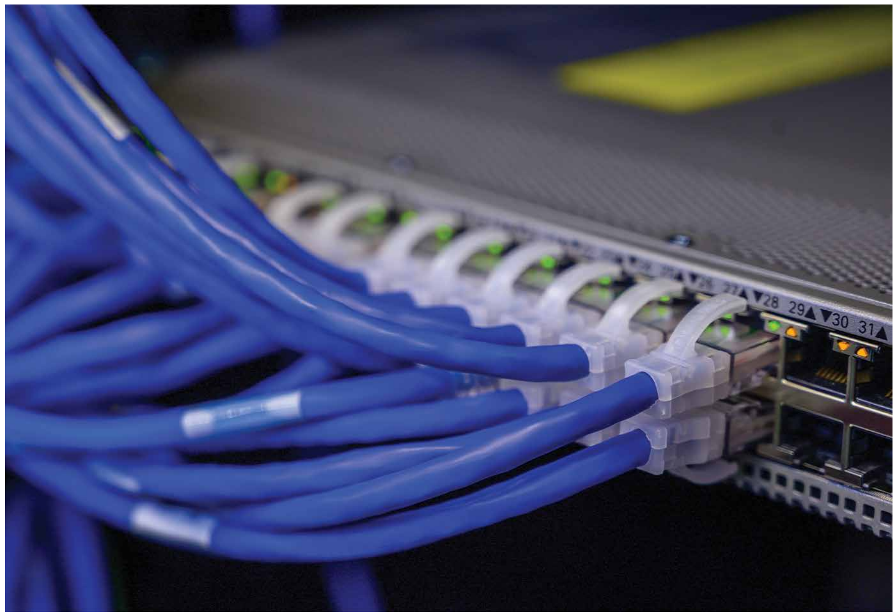
ONU/ROUTER

It is recommended to install the ONU, (See Figure 11), which brings the fiber connection to each subscriber, inside the premise. Some consumers may object to this so outside ONUs must be available. These must be environmentally hardened, and powered, adding cost to the solution. It is recommended to provide a wireless Wi-Fi router as part of this offering, rather than have the consumer provide their own. It is further recommended that a Wi-Fi6 router be provided since this unit is able to support the higher speeds in the premise for a multi-gigabit service.

Figure 10. Splitters in Outdoor Cabinets

Figure 11. Optical Network Unit Installation

11 ESTIMATED PROJECT COSTS



ESTIMATED PROJECT COSTS

To estimate project costs for this study, a number of assumptions will need to be made. By far, the highest cost is the construction of the fiber conduit and the splicing and testing of the fiber network itself. Other costs will include a number of categories of equipment costs, including the data center equipment, fiber distribution cabinets and splitters, drop fiber including installation, and ONTs and Wi-Fi6 routers in the premises. Major project level costs will also include the development of a map-based high-level fiber route plan and an overall project plan, including possibly RFPs for design, construction, equipment sourcing, QA, and systems integration.

One of the advantages of Fiber-to-the-Premises is that a significant portion of the cost can be deferred until the customer is connected for service. Costs will therefore be categorized firstly as the cost per premise passed, and secondly, as cost per premise connected.

11.1 PREMISES PASSED COSTS

FIBER ROUTING PLAN (OPTIONAL)

Once the data center site has been established, if desired a high-level map-based fiber routing plan can be developed. This will allow a refinement of expected cost levels if necessary for the go/no-go decision. A professional firm would need to be selected to perform this work and quotes would be needed to finalize a price, but a plan of this type would typically be in the $50,000 range and take approximately 6 to 8 weeks.

OVERALL PROJECT PLAN

Once the data center site is finalized and the optional map-based fiber route plan is established, an overall project plan needs to be developed. This plan will include possibly preparing RFPs and assisting in selecting vendors and managing the city's interests through to final partner selection. This project plan would typically take 6 to 12 months and would cost in the $200,000 to $300,000 range.

DATA CENTER

The first step involves deciding whether a suitable location for the data center equipment exists or needs to be constructed. It is not possible to provide an estimate for the cost or schedule at this point. Depending on the business model selected, this issue may resolve itself. However, it is assumed for this cost analysis that the data center space has already been secured.

To estimate the equipment cost needed in the data center for an XGS-PON, the primary costs are the OLTs, which connect to each splitter in the field. Two racks of equipment would be more than adequate, with XGS-PON OLTs and supporting gear costing roughly $1.2 million to $1.4 million.

Two more racks of equipment for the core aggregation switches and core routers would need to be added. The cost of these switches and routers would be roughly $600,000 to $700,000. The cost of a VoIP module needed for voice services would be roughly $200,000.

A Network Management System (NMS) for the switches and routers and a similar management interface for the OLTs would also be needed. The cost would be in the order of $200,000, depending on the vendor and level of management support required. This would bring the total network equipment cost in the data center to $2.2 million to $2.5 million, which is an algorithmic estimate based on the number of passings.

For all this equipment, a typical software license and/or service-level agreement would add approximately 15% of the equipment value per year to the ongoing operating costs.

OSP CONSTRUCTION COSTS

The fiber routing plan will dictate the Outside Plant construction activity, the biggest part of the overall cost. Prior to having the fiber routing plan, a rough cost range can be estimated as follows:

A reasonable first proxy for the fiber route miles needed is the number of road miles, which in this case for Reynoldsburg 112 miles.

Typically, a construction company will be hired to build the OSP, including all permitting and restoration, and blowing the fiber through the conduit. They would not usually do any splicing.

Without knowing the exact mix of aerial or underground construction a reasonable assumption of a 50/50 split has been made.

For comparative purposes aerial construction is approximately ten dollars per linear foot, assuming no major telephone pole replacement issues, and represents the lowest construction cost.

Horizontal boring, the method recommended here for the underground plant in the network, has a baseline price of roughly $18 per linear foot, assuming no issues with buried rock, special permitting costs, or other non-standardized situations. This would set a baseline best-case price with a 50/50 split for 112 miles of fiber conduit construction, not allowing for drop fiber, of $8.9 million.

To account for pole replacement, underground rock, and other obstacles, it is prudent to add 20% giving a cost range of $8.9 million to $10.7 million.

ENGINEERING AND SYSTEMS INTEGRATION

A detailed systems-level design needs to be developed and the implementation needs to be managed on a daily basis.

FIBER NETWORK SPLICING ANDQUALITY ASSURANCE COSTS

As the network is being constructed, considerable splicing costs are required, and quality assurance must be conducted to certify and document compliance to both the design and standards. For a build of 16,000 premises passed, this cost can be roughly estimated at $2 million.

FIBER DISTRIBUTION CABINETS

Once the fiber has been brought to the neighborhood, Fiber Distribution Cabinets need to be sited and built to house the 1x32 splitters. As a first estimate, cabinets containing ten 1 x 32 splitters, plus room for growth, serving 200 homes passed, will be assumed. This gives a total of 80 Fiber Distribution Cabinets required.

The splitters themselves can be estimated to cost $720 each. Permitting, pouring concrete slab, placing the cabinet, and splicing cost for each FDC may be estimated at $12,000. Each FTC, including splitters, would therefore be $19,200, yielding a total cost estimate of $1.5 million.

Summary: Costs Per Premises Passed

The sum total of cost estimates for the Premises Passed portion are shown in Figure 12. This yields a cost range of between $1,020 and $1,190 per premise passed, which is within the norm of similarly sized and characterized projects.

11.2 PREMISES CONNECTED COSTS

DROP FIBER AND INSTALLATION

A typical number for a drop fiber connection, including ONT, assuming pre-connectorized cable, is $800 to $900.

CUSTOMER PREMISES COSTS

This will include a WiFi6 router with VoIP port, installation, and test. Costs of this will range from $200 to $500.

Summary: Cost per Premises Connected

A total of $1000 to $1400 per home would not be incurred until a customer is connected. This “success-based” capital represents from 37% to 57% of the total capital spent per customer, depending on a range of cost estimates used.

Premises Passed Costs

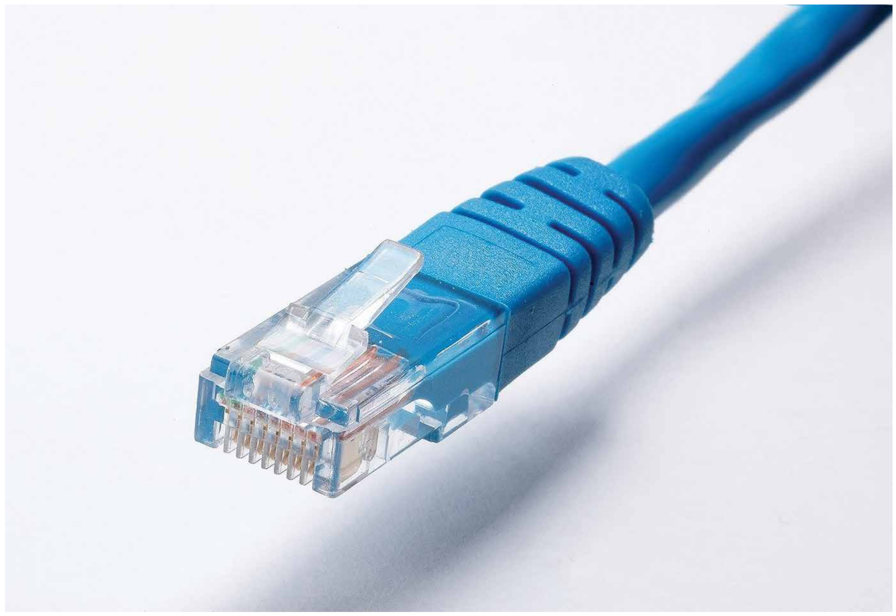
	Low	*High*
Fiber Routing Plan	$0.05M	$0.05M
Overall Project Plan	$0.2M	$0.3M
Headend Equipment	$2.2M	$2.5M
OSP Construction	$8.9M	$10.7M
Engineering Systems Integration	$1.5M	$2.0M
Fiber Splicing/QA	$2.0M	$2.0M
FDCs and Splitters	$1.5M	$1.5M
Total	**$16.35M**	**$19.05M**
Cost per Premises Passed	**$1,000**	**$1,190**

Premises Connected Costs

	Low	*High*
Drop Fiber and Install, Including ONU	$800	$900
WiFi6 Router VOIP Port, Including Install and Test	$200	$500
Cost per Premises Connected	**$1,000**	**$1,400**

Figure 12. Estimated Project Costs

12 ESTIMATED TIMELINE



TIMELINE OVERVIEW

A preliminary view of the project timeline, consistent with other Fiber to the Premises builds of comparable size, would indicate a total project timeline of four years from project launch to completion of the final neighborhood in the build.

The project planning step is most critical, as it examines a number of potential business models and will most likely result in the model that best suits the city's needs. Once this is accomplished, the implementation phase, regardless of the model, should adhere fairly closely to the project timeline for completion as shown in Figure 13.

It should also be noted that the pandemic induced supply chain issues and personnel availability constraints have not yet been eliminated, so partner choice could have an impact on schedule.

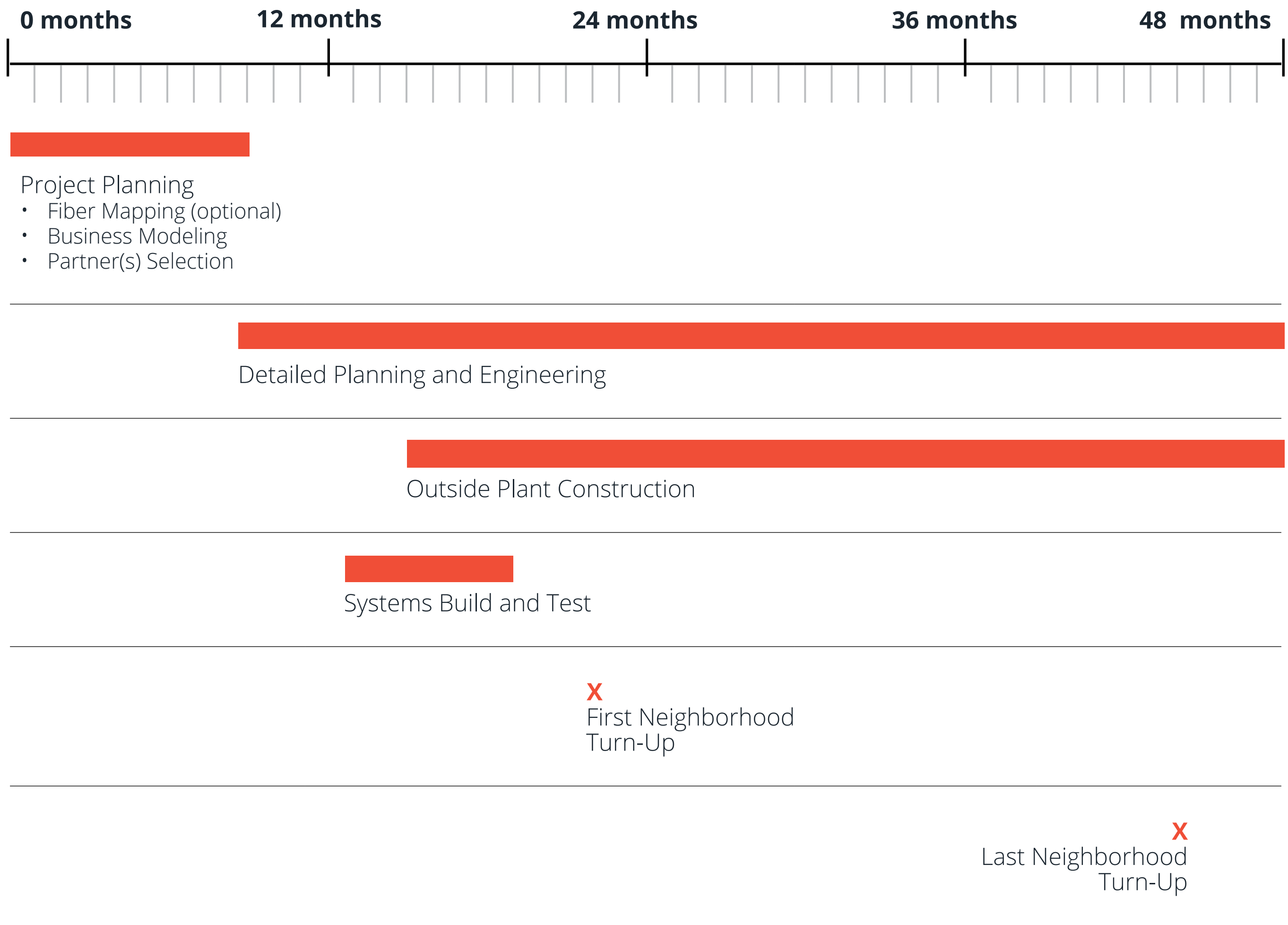
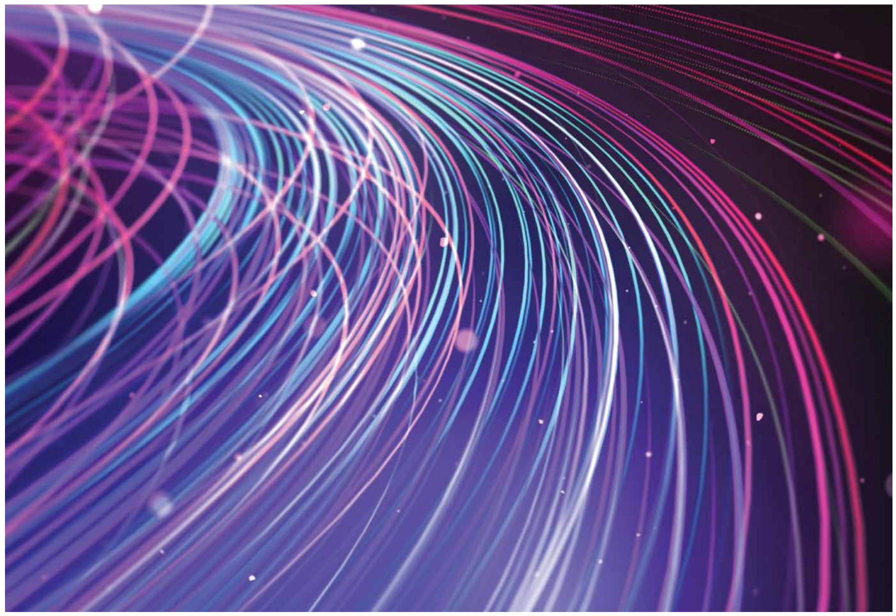


Figure 13. Preliminary Project Timeline

13 BUSINESS MODEL CONSIDERATIONS



BUSINESS MODELS FOR FTTP DEPLOYMENT

There are a number of potential business models or combinations of models for consideration in deploying a Fiber to the Premises Network:

- Municipal service provider
- Open Access wholesale model
- Public/private partnership
- User subsidized
- Complementary services contribution
- RFP

Let us look at each of these alternatives for relevance to deployment in Reynoldsburg.

13.1 MUNICIPAL SERVICE PROVIDER

Many municipal governments have launched their own networks, providing FTTP-based broadband service to their residents. Although most municipals struggled early on, there are many smaller cities and towns successfully deploying their own Broadband Services. This would however require making a significant resource investment, particularly since Reynoldsburg does not provide an electric utility service which could be leveraged.

Looking at the example of Cedar Falls, Iowa, cited earlier, which is comparable in size to Reynoldsburg, that city has a team of roughly 20 people supporting this service and has been providing broadband service for many years. We do not recommend that Reynoldsburg follow this path.

13.2 OPEN ACCESS

A variant of the municipal-owned and operated model is one of Open Access, which is basically a wholesale model. This is very similar to the electric utility model being used in Reynoldsburg today. In this case, a partner would be selected to build and possibly operate the wholesale network, with competitive service providers using it to connect to clients.

Unfortunately, this model has seen very limited deployment and even more limited success in the US.

One interesting development in this area of Open Access, however, has recently occurred. AT&T, the biggest provider of FTTP access in the country, has recently entered into a partnership with BlackRock to create GigaPower, which is committed to building Open Access-based Fiber to the Premise networks. Initially, their focus is on areas outside of AT&T's ILEC footprint, which would preclude Reynoldsburg. GigaPower has stated that both government subsidized, and non-eligible areas would be targeted. Some analysts believe that with the cost of capital needed for these projects now off of AT&T's books, they may use this process to build inside of their own footprint in the future, making them a potential Reynoldsburg partner.

13.3 PUBLIC-PRIVATE PARTNERSHIP

This model is one of the dominant models being used for deployment today across the country. The question then becomes what public funding is being used whether it be federal, state, or local.

FEDERAL FUNDING

Federal government funding has been directed at bridging the digital divide for some years now. With the disruption to society caused by the pandemic, significant additional resources have been made available. The latest of these is the $42.5 Billion BEAD program, which is being allocated to each state for administration according to FCC broadband maps, whose accuracy has been a significant issue. In May of this year a second national version of the map was issued, adding 3 million new locations while deleting 2 million, for a net total of 8.3 million unserved locations being targeted.

Unfortunately, Reynoldsburg, with no unserved or underserved residents per government definition would not qualify for this funding.

OHIO STATE FUNDING

The Ohio Residential Broadband Expansion Grant Program was passed into law and included in the Ohio State Government budget 2022–2023 operating budget.

It is targeting an estimated 300,000 households in Ohio without access to high-speed Internet. The program uses 25 megabits per second downstream and 3 megabits per second upstream as required capability.

This program is being administered through Broadband Ohio. In March 2022, $232 million of grants were made to 11 ISPs for 33 programs covering 43,000 Ohio homes. These providers agreed to build 71 additional programs with their own funding to cover a further 52,000 homes.

Unfortunately, Reynoldsburg, with no unserved or underserved residents per government definition would not qualify for this funding.

LOCAL FUNDING

This option would require the city to provide at least part of the funding to incent a partner to construct a network to serve the city. In return for this subsidization, it would be reasonable to require competitive services, customer service levels, local commitment, and possibly completeness of coverage.

13.4 USER SUBSIDIZED

LOCAL IMPROVEMENT DISTRICT

One interesting model was developed by the city of Amman, Idaho. Residents in a given neighborhood can decide to opt-in to become part of a Local Improvement District, prior to fiber construction.

If enough opt-in to the $3200-$3600 fee, construction begins, and this fee can be subsidized over 15 years with low-interest loans. Once opted in, an open access system provides users with low-cost monthly fees (typically $20-$25 per month for one gig access.) If enough users do not opt in the neighborhood is not built.

The service is up and running in the city today with five different providers offering their service. To our knowledge, this model has not been utilized anywhere else.

13.5 FIBERHOODS

Since the outside plant construction is such a major part of the overall cost, it is worthwhile trying to optimize the build in sync with the greatest number of customers likely to sign up for service. Google Fiber has pioneered this process called “fiberhoods” which surveys residents in each neighborhood to determine intent to sign on. Customers signing on would have their connection fee waived. If enough customers sign on, then the neighborhood is built. This process is really an effort to get income flowing into the financial model as soon as possible.

13.6 SUBSIDIES

Some municipals have raised property taxes to fund fiber-to-the-premise builds, and some of taken out long-term bonds. As noted above, many of the early FTTP builders have not yet been able to achieve financial viability.

Some major property developers have partnered with service providers to allow only FTTP-based access in their development. This is one of the principal reasons the MSOs have developed FTTP-based solutions.

13.7 COMPLEMENTARY SERVICES CONTRIBUTION

Since the bulk of the cost of deploying an FTTP network is the outside plant construction needed to deploy the fiber all around the city, a logical question becomes one of what else could the fiber be used for to help offset the cost.

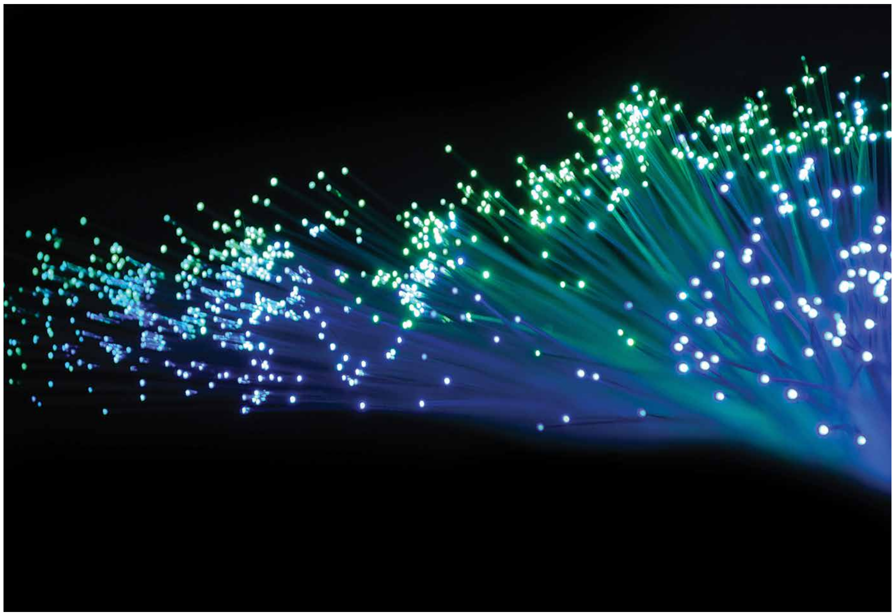
One common use is for the provision of fiber to the major wireless providers, who need to deploy massive amounts of new fiber for their 5G network upgrades. There are also uses such as Smart Grid for transportation, and Smart City applications for security and safety.

An interesting opportunity may be the provision of gigabit service levels to schools, which will be needing much more bandwidth in the future as AR/VR based applications become available over the next few years. This would be a good opportunity to explore further, not only for its own merit but also as a potential co-funding opportunity with the school authorities.

13.8 RFP

One reasonable way to proceed would be to issue a public RFP, including the appropriate variants described above to find a suitable partner.

14 POTENTIAL PARTNERS



FTTP PARTNERS PROSPECTS

Depending on which business model is chosen, there are a number of potential partners available as follows:

AT&T

AT&T is the dominant provider of telephone service in Reynoldsburg. They are providing FTTP service to a small segment of the city and DSL service everywhere else.

The company is publicly committed to passing 30 million out of 53 million total premises with fiber by the end of 2025 and is at 24 million fiber passings as of March 2023.

Since the FTTP services in Reynoldsburg are offered at one gig symmetrical, and Reynoldsburg is not among the 100 cities announced by AT&T as being upgraded to10Gig XGS-PON, it is unlikely that the entire city footprint will be built out with fiber on their own accord.

They have engaged in a number of public/private partnership deals recently, however, and may be amenable to some kind of joint project, either directly, or in the longer term via GigaPower.

METRONET

Metronet, an Indiana-based fiber provider, has been in the business for many years and is currently building a system in Findlay, Ohio.

BRIGHTSPEED

Brightspeed is already building in 12 cities in Ohio and planning to pass 380,000 locations over the next few years.

ALTAFIBER

Altafiber (formerly Cincinnati Bell) is building in a number of locations around the state.

HORIZON

Horizon, the incumbent phone company in Chillicothe, Ohio, is building in 13 new communities in Ohio.

LIT COMMUNITIES

Lit Communities, a relatively new provider, is operating an Open Access system in Medina County, Ohio.

GOOGLE FIBER

Google Fiber, while not currently building in Ohio, is re-entering the market after a pause with a number of new projects in several states. Google has one of its 23 global data centers just up the road in New Albany and has a Google Cloud Access point in the Corlogix data center in Columbus.

POINT BROADBAND

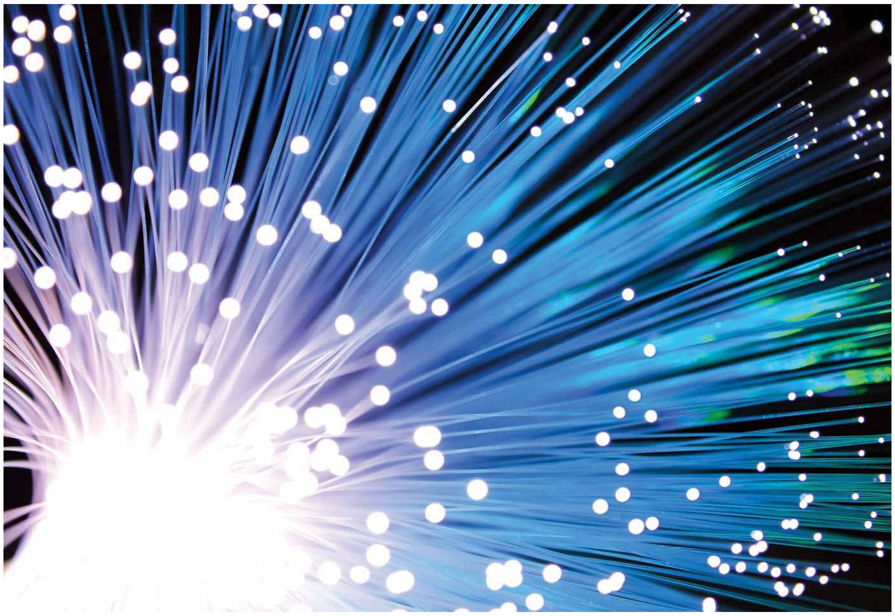
Point Broadband, based in Alabama, is building in a number of states and focuses on smaller communities.

ATLANTIC ENGINEERING

Atlantic Engineering, based in Georgia is an active systems integrator, building for example an 80,000 homes-passed system in 2022 in Fort Collins, Colorado.

This is not an exhaustive list but is indicative that a number of potential partners are out there to assist in realizing an FTTP-based fiber network in Reynoldsburg.

15 CONCLUSIONS AND RECOMMENDATIONS



15.1 CONCLUSIONS

Broadband networks have a continuous need for increased speed, as user devices become more powerful, applications become more sophisticated, and people spend more time and rely more and more on Internet-based services to enhance the quality of their lives.

The challenge for Internet Service Providers is to stay ahead of user needs while deploying technology that can easily and cost-effectively be evolved for future use over a multi-year timeframe.

Until recently, the most successful offering has been provided by the cable operators (MSOs) who have had the largest market share nationally for some time.

Reynoldsburg is well served with this technology, with universal coverage by the incumbent MSO and an overbuilt coax network providing a second choice of provider to over half of the city. These networks appear to be upgraded to be able to supply one gigabit downstream albeit with a limited upstream connection to every resident.

The incumbent MSO has publicly committed to upgrading its entire national network to DOCSIS 4.0 by the end of 2025. Reynoldsburg will most likely be at the lowest of three tiers of the upgrade, but it will nevertheless provide the two-gigabits downstream and one-gigabit upstream capability. The overbuilt coax system owner has not publicly divulged their plans for any further upgrade.

Fiber-based service is being provided to a small percentage of residents by the incumbent ILEC (telephone service) provider, with low-speed DSL service available to the rest of the city.

It is unlikely that an FTTP network for all residents will be constructed over the next several years without city government involvement.

Should the city choose to engage one of a number of potential business models to provide assistance in the construction of a fiber-based network, this could be in service beginning in mid-2025 with completion at the end of 2026. Given the relatively small geographic footprint of the city and a significant percentage of aerial utilities, the cost of such an FTTP network would be at the low end of similar-sized networks.

If the AR/VR applications noted in the report become widely adopted over the next several years, the symmetrical 10-gig capability of an FTTP network would be of great utility to the residents of the city.

15.2 RECOMMENDATIONS

1. It may be useful to conduct a survey of residents to determine their views on current Internet service and desire for potential higher speed service.

2. If a more precise estimate of costs is necessary, a fiber mapping exercise could be conducted.

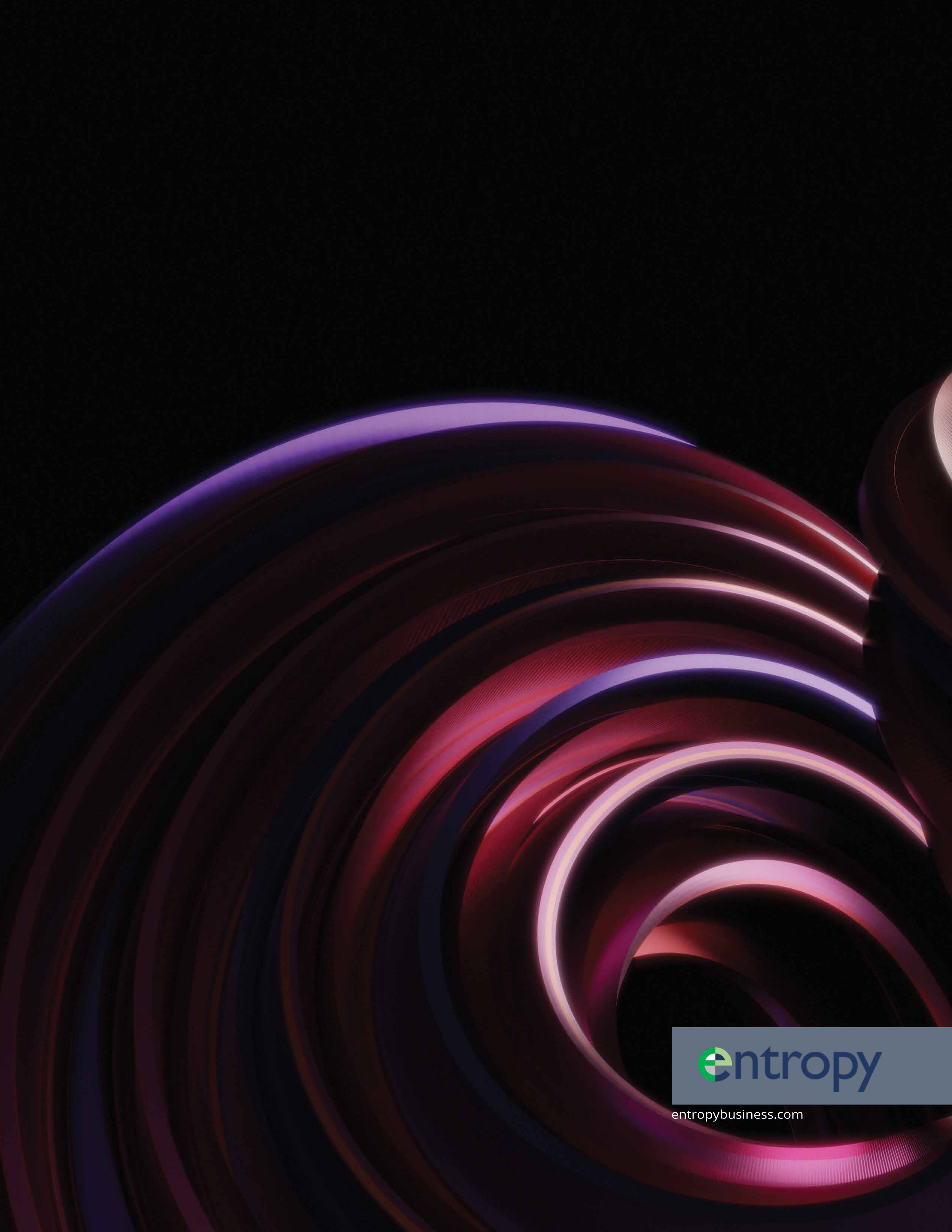
3. The business model alternatives outlined in this report should be analyzed for appropriateness to the circumstances and preferences of the city.

4. If necessary, depending on the model chosen, a headend location within the city would need to be identified prior to any further network planning.

5. Develop, issue and analyze an RFP for a range of FTTP proposals. OR

6. Engage potential partners one by one for analysis.

7. Approach school authorities for potential interest in an FTTP-based pilot program for future educational student needs.



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