MAY 2021

Future Proof: Economics of Rural Broadband

COMPARING TERRESTRIAL TECHNOLOGIES & INVESTMENT CONSIDERATIONS TO MEET INCREASING CONSUMER BROADBAND DEMANDS

A Greenfield Rural Broadband Case Study

A white paper prepared by Vantage Point Solutions, Inc.
for the Foundation for Rural Service

FOUNDATION FOR RURAL SERVICE

This white paper was made possible by the generous support of the Rural Independent Competitive Alliance (RICA).

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Executive Overview

As broadband demand increases over time, it is important to evaluate broadband technologies both from short- and long-term cost perspectives to ensure that a network being built now will be capable of satisfying user demand over the useful life of the facilities rather than having to rebuild them repeatedly to keep pace with such demand.

In addition to taking stock of anticipated increases in user demand over time, the density of the area to be served plays a large part in evaluating various broadband technology options. A technology that may be feasible for deployment in an urban area may not be feasible or as efficient in a rural area where users are scattered thousands of feet or even miles apart.

This document reviews current "last mile" broadband technologies from a rural deployment perspective. These include:

- Fixed wireless
- Hybrid Fiber Coax (HFC)
- Fiber to the Premises (FTTP)

This paper examines the key technical, deployment, and investment characteristics of each technology in the context of an actual "greenfield" rural case study area to illustrate the short- and long-term economic considerations. For purposes of this paper, "greenfield" refers to building a network from scratch and not relying on any existing infrastructure in the area. A greenfield build is required for most broadband providers that were successful in the Connect America Fund (CAF) Phase II auction, the Rural Digital Opportunity Fund (RDOF) auction, and many other state and federal broadband grants and loans. In a greenfield build, the provider's network does not make use of any existing copper or fiber infrastructure or towers, antennas, or other wireless infrastructure, because they either do not currently provide any service in this area or the facilities are not usable for some reason for the new broadband network.

Greenfield Analysis

Greenfield deployments are those which are not constrained by prior work in the deployment area: where the construction "field" is "green," or untouched by pre-existing parameters.

Analyzing greenfield builds is useful in comparing technologies, as each is evaluated from the same starting point. Hence for this paper, all networks are considered new implementations.

Wired Networks

When it comes to **wired** networks in a greenfield scenario, it would be rare that the broadband provider would use any technology other than Fiber to the Premises (FTTP). Since most of the cost associated with deployment of a landline network is the labor cost associated with placing the cable, it would be unlikely that the provider would place any type of copper or HFC cable in a greenfield build given the substantially better broadband performance provided by a fiber cable that can be installed at the same price. Any copper or HFC technology installed today will likely reach the end of its useful life long before it reaches the end of its economic life.

Wireless Networks

A greenfield design of a **wireless** network involves the installation of towers, antennas, electronics, and fiber to backhaul the broadband signals from these towers. But assessing the efficiency of a wireless network in a greenfield scenario also requires an understanding of spectrum capacity and capabilities. Like a prism of different colors of light, the wireless spectrum is also divided into well-defined bands. Some of these bands are licensed (meaning the provider has exclusive or priority rights to the use of the spectrum) or unlicensed (meaning that anyone can use the spectrum). The Federal Communications Commission (FCC) has also defined a third class of spectrum that is often referred to as "lightly licensed." With lightly licensed spectrum, any provider can use the spectrum, but they must coordinate with other providers who desire to use the same spectrum to help minimize interference between each other. Certain spectrum bands have been designated for broadband use – from as low as 600 MHz to over 70 GHz. Lower frequency spectrum travels farther and penetrates objects better than higher frequency spectrum, which makes lower frequency spectrum better suited for rural applications. Regardless of the frequency, the quantity of spectrum is the primary determining factor in how fast of broadband the provider can offer and how many customers can be served.

Unfortunately for rural customers, there is very little low frequency spectrum (below 2 GHz) available for broadband use, so this spectrum is unable to meet most customers' broadband needs even as it offers the best propagation characteristics that would be needed to span great distances in rural areas. Meanwhile, frequencies between 2 GHz and 6 GHz are often referred to as the mid band and can deliver broadband speeds in the range of a few hundred megabits per second (Mbps) over a few miles. Much of the mid band spectrum used for broadband is unlicensed or lightly licensed so the spectrum must be shared with existing users of the band or other broadband providers, reducing the broadband speed that can be offered and the number of users that can be served. Finally, much more spectrum is available for broadband providers in the high frequency bands – which are generally above 30 GHz and are often referred to as millimeter wave (mmW) bands. The mmW bands have enough spectrum to deliver gigabit broadband speeds. Unfortunately for rural customers, there is a trade-off between capacity and propagation in the use of spectrum – these higher speeds can only be achieved over distances of less than a mile and often only a few hundred feet.

"Greenfield" Choices

To assess the viability and value of these various wired and wireless networks in a rural greenfield build, we evaluated network options based on their initial cost and over a 30-year time horizon. Using a shorter time frame would make little sense, as it would artificially reduce and disregard the full economic benefit conferred by network assets like fiber and towers that have a useful life of 30 years or longer. When one conceives of broadband deployment as the construction of 21st century infrastructure, it is reasonable to expect and demand that such investments will be capable of lasting and satisfying user demand for decades – such as 30 years – after construction, subject to reasonable operating expenses and minimal periodic capital expenses for upgrades and repairs. It is reasonable therefore to use this time horizon in looking at the relative total costs of ownership for various network architectures.

When considering the total cost of ownership over 30 years rather than a shorter time horizon, as explained in this paper, network economics based upon sound engineering practices indicate that FTTP networks deliver greater value for fixed broadband as compared to wireless or HFC networks in light of the costs invested and capacity realized. Not only do FTTP networks have a lower 30-year cost of ownership, they also have a greater revenue potential when compared to the other technologies because of their greater broadband capacity.

By contrast, in the case study we analyze in this paper, at the end of 30 years we estimate that a mid band wireless network may cost 30% less than a FTTP network, but its broadband speed would be 10 times slower at the start and would likely be more than 3,000 times slower at the end of that 30-year period. We also believe this analysis of costs is conservative because it does not include other costs associated with the wireless network such as the commercial power required for each of the tower sites and the cost of the wireless spectrum – making the long-term cost of the wireless network even higher. FTTP networks are completely passive (i.e., no electronic components or external power) between the electronics in the central office (or cabinet) and the customer premises. Since this passive FTTP can reach 20 or more miles from the central office electronics to the customer, FTTP is able to cover an area of nearly one thousand square miles. When considering networks capable of delivering gigabit speeds, this same area would require ten to twenty towers for a wireless broadband design or possibly hundreds of fiber nodes in an HFC design.

Similarly, when analyzing a mmW-based wireless network in a greenfield case study, this paper finds that the initial investment required is likely to be more than three times higher than it would be for a FTTP network, and the mmW wireless network is likely to cost approximately five times more than a FTTP network over the 30-year horizon – even as the mmW network would have lower broadband performance now and in the future. Like the mid band network, we believe these estimates are conservative because many of the operational costs for a mmW-based wireless network were not included such as commercial power for the tower sites and the potential cost of spectrum. Comparatively, the FTTP network is substantially less expensive over the next 30 years and is estimated to provide broadband speeds that are more than 300 times the speed available on a mmW network at the end of this period.

As this paper explains, our analysis ultimately reveals that, over a reasonable time horizon based upon the anticipated and expected useful life of broadband infrastructure, a FTTP deployment represents the most efficient means of providing the highest level of broadband in a greenfield deployment. Moreover, fiber networks will provide not only fixed broadband directly to residential and business users well into the future, but also the foundation of future wireless services in these areas. Indeed, even as fiber provides the backbone, wireless services will certainly continue to be an important tool in the toolbox as broadband networks are designed and deployed in the future. They can be cost effective, particularly in high density areas where the high cost of laying fiber and the more limited propagation characteristics of higher-performing spectrum bands impact network economics differently than in more sparsely populated rural areas. **This paper, however, focuses specifically on network economics and efficient deployment choices over time in lower density unserved rural areas where greenfield deployments are needed – and concludes that, even where upfront investment costs may be higher, FTTP represents the most cost-effective means of delivering sufficient bandwidth for users now and for decades to come.**

Broadband Demands

Only 20 years ago, it was hard to imagine why someone would need a broadband speed of even just 1 Mbps. Today, the national average broadband speed has increased by 150 times that. As broadband speeds have rapidly and consistently increased over the last 20 years, many areas of our lives have come to depend upon the capabilities provided by such access. During the pandemic over the last year, the need for high quality, fast, and reliable broadband has become critical to our education, retail, healthcare, public safety, and entertainment – nearly every aspect of our lives. Given growth trends that just continue apace, there does not seem to be a plateau in sight for the increasing broadband demands or broadband usage.

The average broadband speed in the United States was 146.1 Mbps in October 2019 according to the Federal Communications Commission's (FCC's) Tenth Measuring Broadband America Report.[1] This speed has increased by an average of 35% annually since the first report in 2012 and 54% annually since the FCC's Eighth Report just two years ago.[2] At this rate, the average broadband download speed will exceed 1 Gbps within the next 6 years.

[1] FCC's Tenth Measuring Broadband America (MBA), Fixed Broadband Report, January 4, 2021.
[2] Ibid, page 7.

Cisco's Annual Internet Report (2018-2023) White Paper[3] shows a far more conservative 20% annual growth rate from 2018-2023. Using the average speed from 2012 to 2019 from the FCC's MBA report but applying the more conservative 20% increase from the Cisco Annual Internet Report, the average speed will be 1 Gbps by 2030 as shown in Figure 1. In addition, OpenVault estimates that the monthly weighted average data consumed by subscribers in 4Q20 was 482.6 GB, up 40% from 4Q19's weighted average of 344 GB, and up nearly 26% quarter-over-quarter from 3Q20. Furthermore, 14.1% of weighted average subscribers use over 1 TB of data per month.[4]

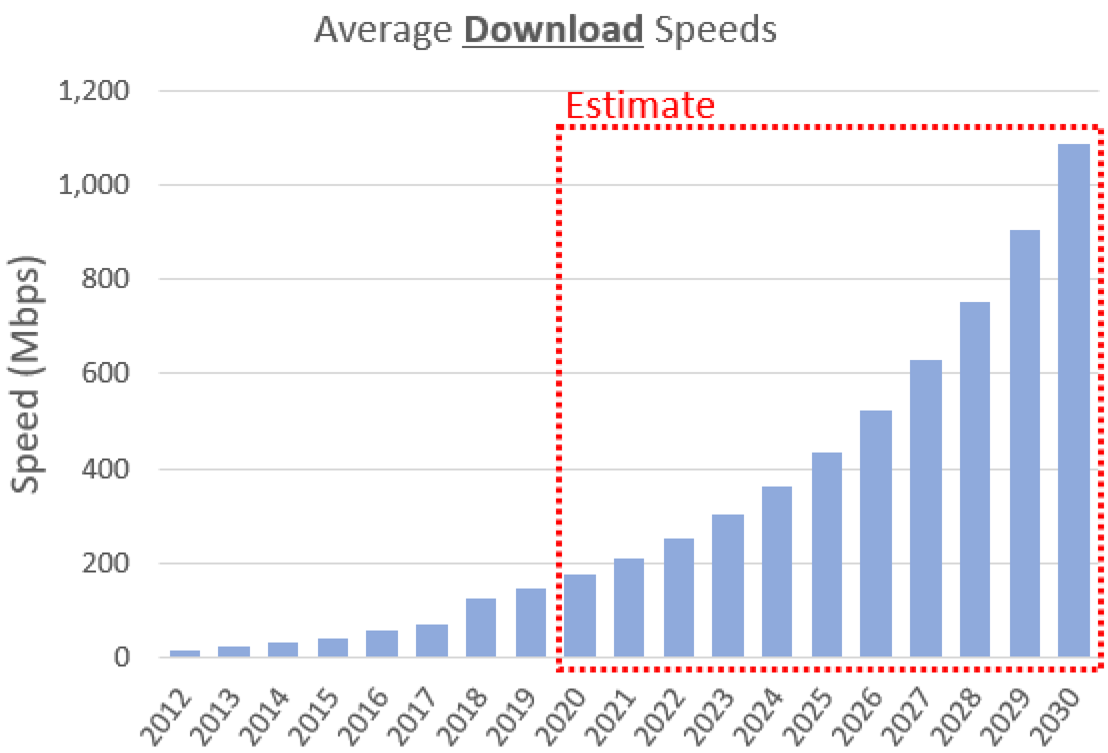

Figure 1: Estimated Broadband Speeds

Network Architectures for Delivering Terrestrial Broadband

At the dawn of the broadband era, networks based on twisted-pair copper cable and coaxial cable which were originally developed to deliver voice or video services were adapted to deliver broadband services. Using new modulation methods and the availability of new spectrum, wireless technologies have likewise been used to help meet the customer's ever-increasing broadband demands. In more recent years, as demands for higher speeds and better performance have increased, wireline broadband providers have placed fiber-fed electronics closer to the customer and reduced the amount of twisted-pair copper and coaxial cable in their networks. Delivering broadband over twisted-pair copper networks uses Digital Subscriber Line (DSL) technologies. When fiber is used

[3] Cisco Annual Internet Report (2018-2023) White Paper, Updated March 9, 2020. https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html

[4] OpenVault Broadband Insights Report (OVBI), 4Q20

to shorten twisted-pair copper loops to increase broadband speeds, it is referred to as "Fiber in the Loop" (FITL). When fiber is used to replace coaxial cables, it is referred to as a Hybrid Fiber-Coax (HFC) network. Similarly, wireless network operators have increasingly sought to deploy or secure more fiber to reach their towers and in turn have moved their fiber-fed towers closer to the customer to reduce the portion of the network that relies on spectrum.

With this as historical backdrop, there are several alternative architectures to consider when implementing a broadband network today. Each of these alternatives has trade-offs when considering broadband speed, reliability, scalability, capital expense, operational expense, and speed of deployment. These factors and others determine the network's total cost of ownership, which impacts not only the amount of end user revenues that will be needed but in some areas the amount of state or federal support required to sustain the network and services. Our goal herein is to determine the most practical broadband network to deploy to areas currently lacking broadband – a "greenfield" build in unserved areas – that will meet and keep pace with customer broadband needs and minimize total cost of ownership over a reasonable time horizon. The broadband network technologies this paper considers are shown in Table 1.

Technology	Overview	Broadband Speed Limitations
Fixed Wireless	Fixed wireless is a location-based broadband service that consists of a base station with an antenna at a central location (normally mounted on a pole or tower) and equipment at the customer premises used to communicate wirelessly with the base station. To provide the necessary capacity, the base station often relies on fiber for its upstream connection.	• Amount of spectrum • Distance from tower • Number of customers served on shared basis by tower/sector • Other RF interference • Lines of Sight/Obstacles (trees, hills, buildings, etc.) • Weather (some bands)
Hybrid Fiber Coax (HFC)	HFC networks have historically been used by cable television operators to deliver video programming and more recently broadband. These networks leverage existing investment in coaxial cable plant. Increasing the number of electronic nodes in the field increases broadband speeds by reducing the number of customers on the coaxial cable segment. The electronic nodes are connected to the network using fiber.	• Quality of field amplifiers • Number of customers on shared coax segments • Noise on coax cable
Fiber to the Premises (FTTP)	FTTP networks remove the copper/coax and wireless bottleneck from the network and connect fiber directly to the customer premises. The characteristics of fiber allow the broadband signal to travel much farther (20 miles or more) without requiring additional field electronics.	• The limits of broadband speed over fiber have not yet been found – Speed is only limited by the electronics attached to the fiber.

Table 1: Broadband Access Technologies

Network Design Choices

Not all broadband networks are created equal, and each has different strengths and shortcomings. A broadband network must be architected to provide or address the following:

- Fast broadband speeds that satisfy current demands and can keep pace with future broadband demands
- High reliability
- Low latency
- High monthly usage allowances
- Balancing of initial investment and ongoing operating costs – the "total cost of ownership"

Both wireless and wireline technologies are converging on a similar network topology. The common network topology in both cases normally consists of a fiber optic backbone (sometimes referred to as backhaul or the "second mile"), an aggregation point in the field, an access network (wireless or wireline), and customer premises equipment. In other words, the key distinction between networks comes in what technology is used in (and how much equipment must be deployed as part of) the "last mile" access network. This can be seen in Figure 2.

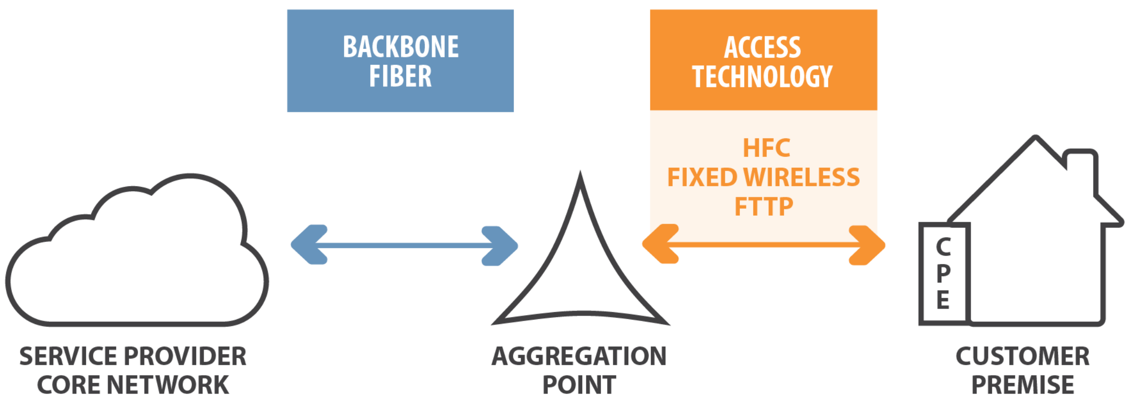

Figure 2: Basic Network Points

Because it is costly to purchase, install, maintain, upgrade and supply power to fiber-fed electronic aggregation points, network designers try to minimize the number the number of field electronics required. Increasing the number of aggregation points also reduces network reliability since they are susceptible to electronic failure and power outages. Technologies that allow longer distances between the aggregation point and the customer – that, in a sense, make the "last mile" longer – are therefore desirable, but they often come with tradeoffs such as slower speeds for wireless networks (due to spectrum propagation limitations) or increased investment for HFC networks (due to the need for more cable and amplifiers). For example, when using millimeter wave (mmW) wireless technologies, the aggregation point (the point closest to the customer with active devices that require commercial power) needs to be within several hundred feet of the customer, whereas the aggregation point for a fiber network can be 20 or more miles from the customer since the signal loss experienced by light on a fiber is much less than the free space loss of these high frequency radio frequency signals in air.

Technical & Economic Limitations of Networks in Rural Areas

Our focus in this paper is on identifying cost effective last mile broadband technologies for deployment in unserved rural areas. If one were considering sheer performance capabilities alone, FTTP would indisputably prevail - other last mile technologies such as HFC cable or wireless signals will introduce a broadband bottleneck that limits speed at some point in the transmission. This can be seen in Figure 3.

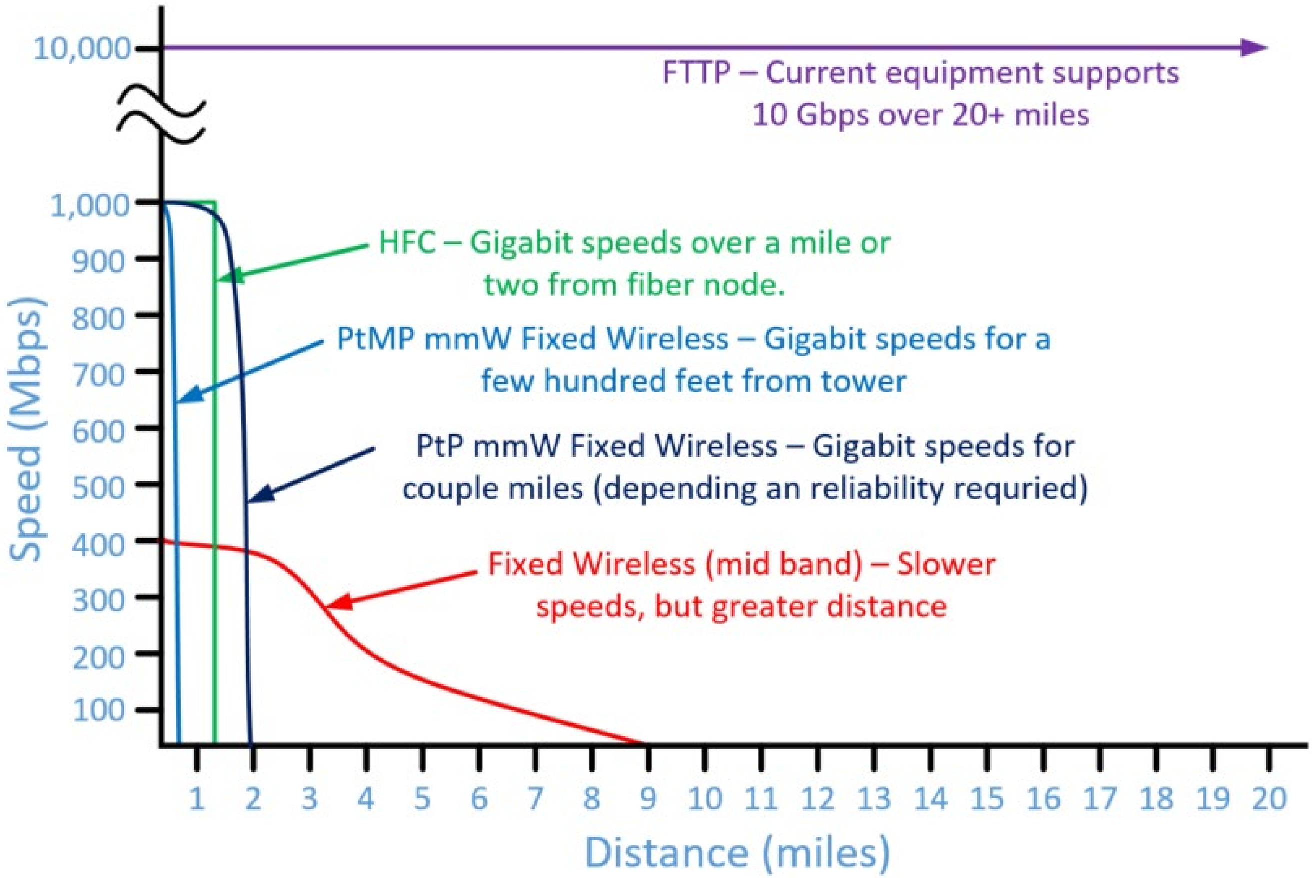

Figure 3: Speed vs. Distance for Broadband Technologies

Because of this performance bottleneck and the fact that most of the construction cost for a wireline network is in the installation, it would be rare for a broadband provider to install any other wireline technology than fiber when starting from scratch. The only time an HFC network would be practical is when the broadband provider is extending an existing HFC network and trying not to abandon its existing investment in coaxial cable – in other words, not in the case of a "greenfield" build or expansion effort into new unserved areas.

Figure 3 also makes it clear why HFC or fixed wireless mmW networks have rarely been used to provide broadband outside of relatively densely populated areas such as cities or town centers. In many rural areas, the distance between customers is so large that, in many rural areas, every customer or two would need its own fiber aggregation point for a provider to deliver higher speeds using HFC. By contrast, FTTP can deliver this level of service for 20 or more miles, allowing each aggregation point to serve many more locations in a rural area.

With the tradeoffs of cost and performance as between HFC and FTTP being relatively clearly tilted in favor of FTTP deployment, this leaves us with the question of whether wireless solutions represent a viable alternative to FTTP networks in rural areas when considering these same tradeoffs noted above – cost, reliability, and performance indicators like speed and latency. With respect to speed, Figure 3 also shows the interrelationship between speed and distance when leveraging fixed wireless technologies for last mile connectivity. When using mmW spectrum, for example, a broadband provider can offer gigabit services, but only over very short distances (only a few hundred feet using point to multipoint systems where a signal central antenna serves multiple customers). When using mid band spectrum, the wireless broadband provider can reach locations at greater distances, but at much lower speeds. This again stands in contrast to FTTP where, as noted previously, the aggregation points for delivery of service at very high speeds can be 20 miles or more away. With these tradeoffs for performance identified, this then brings us to the question of cost – and, in particular, the factors that affect the total cost of ownership of these networks over their useful lives.

Costs and Cost Drivers

As fiber becomes a larger portion of all broadband networks (both wireless and wireline) the cost to install fiber cable become a larger consideration for all networks. The primary factors that determine the cost of cable installation include:

- Type of soil for buried cable or condition of pole for aerial
- Existing underground facilities to work around
- Existing cables on pole infrastructure to relocate (make ready)
- Environmental and Rights of Way

The installation costs of a cable (either fiber optic or coaxial) can be four to ten times the cost of the cable itself. Because of this, there is little difference when comparing the installed cost of a fiber cable and a coaxial cable. Additionally, as noted earlier, HFC networks have significantly more electronics required in the field that must be purchased, installed, and maintained – rendering them a higher-cost option in rural areas even as they deliver lower performance.

This then brings us to the largest cost driver of deploying a rural broadband network – distance. As the distance between customers increases, the network investment needed to serve these customers – whether via wired or wireless “last mile” technologies – also increases. Not only is there more network investment in cables, towers, and electronics, but there are also fewer customers over which to spread this network investment. As the area becomes more sparsely populated, the end user revenues alone can no longer support the network investment.

To minimize the total cost of ownership, any network should have a useful life that is as long or longer than its economic life. In other words, the network should have enough capacity and scalability to continue to meet user demands over the expected life, which is often 5-10 years for electronics and 30 years for cable/wires and towers. In the following section, we will examine three case studies. Fixed wireless, HFC, and FTTP are examined, with each technology engineered to serve a typical rural area and the costs compared.

A Word about Satellites

We do not consider satellite technology in this paper because the scope and economics of a satellite network are dramatically different than a terrestrial broadband network. However, they both must obey the laws of physics. Satellites – both geostationary earth orbiting (GEO) and low earth orbiting (LEO) – all share the same spectrum and will be limited by both the wireless link to the customer or the wireless link to the gateway.

In the coming years, satellite broadband will continue to fill a niche with customers numbering in the hundreds of thousands. We focus on terrestrial broadband in this paper, as we believe it will continue to be the predominant broadband technology for the foreseeable future for most customers given its higher speeds, greater capacity, more reliable service, and the difficulties satellite providers will have in scaling to the millions of customers that lack broadband today.

Comparing Broadband Access Technologies

Many of the recent grant and FCC support programs such as the Connect American Fund (CAF) Phase II auction Rural Digital Opportunity Fund (RDOF) auction, Rural Utilities Service ReConnect grants and loans, and a variety of state and national grant programs have been awarded to broadband providers that currently do not have any facilities in the areas that they were awarded. Because of this, and to attempt to make “apples to apples” comparisons among the various technologies evaluated in this paper to the greatest extent possible, we focus here on deploying a broadband network in a “greenfield” application, similar to what is being done in many rural areas today. A greenfield build does not leverage any existing cable or network that is currently in place: either because the provider does not own an existing legacy network in the area, or often because the existing network consists of assets (such as copper cable) that are more than 30 years old and inadequate for providing the needed broadband services of today.

For this comparison then, we will focus on three common access network technologies that are used to provide broadband to rural customers:

1. **Terrestrial Wireless** – These consist of network towers, normally served by fiber, placed throughout the service territory. Broadband speeds can generally be increased by adding more towers and locating them closer to the customer, which requires the installation of more fiber.
2. **Hybrid Fiber Coax (HFC)** – These networks are widely used by cable television providers since they can leverage existing coaxial cable which has been the most common medium to deliver video for more than 50 years. Fiber nodes are located throughout the serving area and connect to the coaxial cable plant which uses frequently spaced amplifiers to maintain proper signal levels. Generally, broadband speeds are increased by deploying more fiber nodes to reduce the number of customers served by each.
3. **Fiber-to-the-Premises (FTTP)** – A FTTP network consists of fiber all the way to the customer premises. Fiber cable can carry the broadband signal for more than 20 miles without any reduction in broadband speed (unlike wireless or older copper wireline technologies) or requiring any field electronics (such as amplifiers needed by HFC).

For each of these three access technologies we will determine both the initial and long-term capital expenditures (CapEx) required to support the network and make some observations about the operating expenses (OpEx) required to maintain the network once built and as services are delivered atop it.

Deployment Economics Case Study

Sample Rural Area

To compare the costs of deploying broadband using various technologies, we applied network layouts and cost estimates to a real area considered “typical” for a rural build. The area selected, in western Iowa and eastern South Dakota, reflects the kind of population density, difficulty of construction, and terrain that Vantage Point sees in many rural deployments. Indeed, this territory, around Hawarden and Akron, is representative of an “average” area that may be the focus of an RUS ReConnect area or the subject of a FCC CAF Phase II or RDOF auction, although many areas may be more difficult and expensive to serve especially for a wireless network. The area can be seen in Figure 4 (area in orange). Details associated with the area are shown in Table 2.

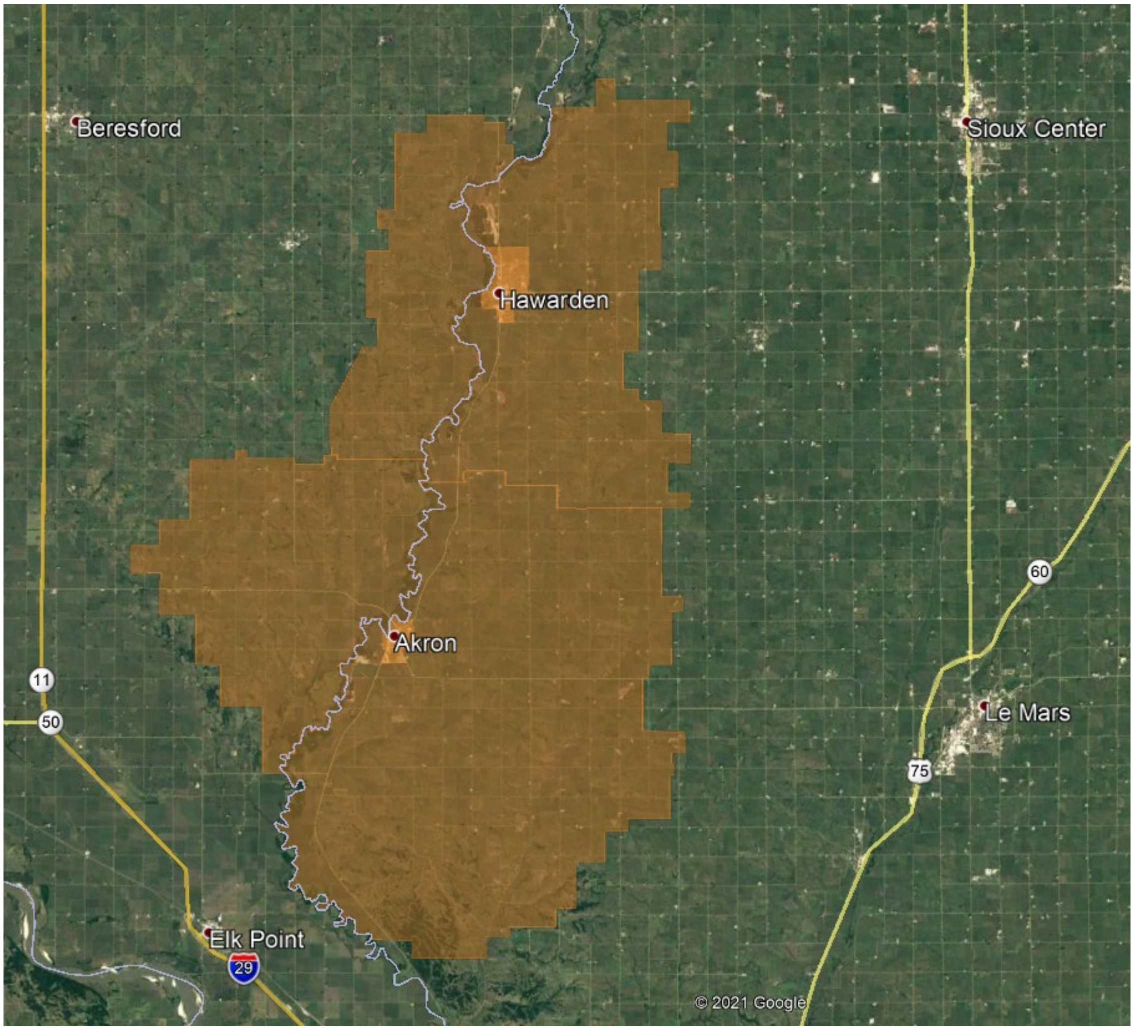

Figure 4: Rural Hawarden and Akron Example Area

Square Miles	336
Locations	1215
Average Density (Loc./Sq. Mile)	3.6
Assumed Subscriber Penetration	70% (856 Subs)

Table 2: Rural Hawarden and Akron Details

With the area identified, we turn now to analyzing the initial and long-term costs of a greenfield network deployment using three different access technologies: Fixed Wireless (both mid band and mmW), HFC, and FTTP.

Fixed Wireless Design

Two wireless networks were analyzed – one that would provide 100/20 Mbps to every customer and the other that would provide 1 Gbps/500 Mbps broadband (as required by the RDOF gigabit tier). The networks relied on spectrum, equipment, and technology that is commercially available today. It was assumed that the provider had access to adequate spectrum to provide these services, but no costs were included in the financial analysis for the acquisition of this level of spectrum, making these estimates rather conservative.

100/20 Mbps Wireless Service Design

The 100/20 Mbps design uses 3.5 GHz Citizens Broadband Radio Service (CBRS) mid band spectrum to serve most of the area. For some housing clusters, 60 GHz mmW spectrum was used because it was determined to be more cost effective because of the relatively greater population densities. It is assumed that the broadband provider has access to enough mid band spectrum to provide 100/20 Mbps service, which may be overly optimistic for many providers. If we assume a spectral efficiency of 5 bits per second per hertz (bps/Hz) the provider would need 24 MHz of spectrum for a single user. To serve a small number of customers in this sector, the spectral requirements would likely be at least 4 to 6 times this amount (100 to 150 MHz). Covering the territory would require 8 fiber-fed towers, as shown in Figure 5. The cost estimate assumes construction of the fiber backhaul and the 8 tower locations to cover all locations. The CPE costs are assumed based on a 70% subscriber penetration rate.

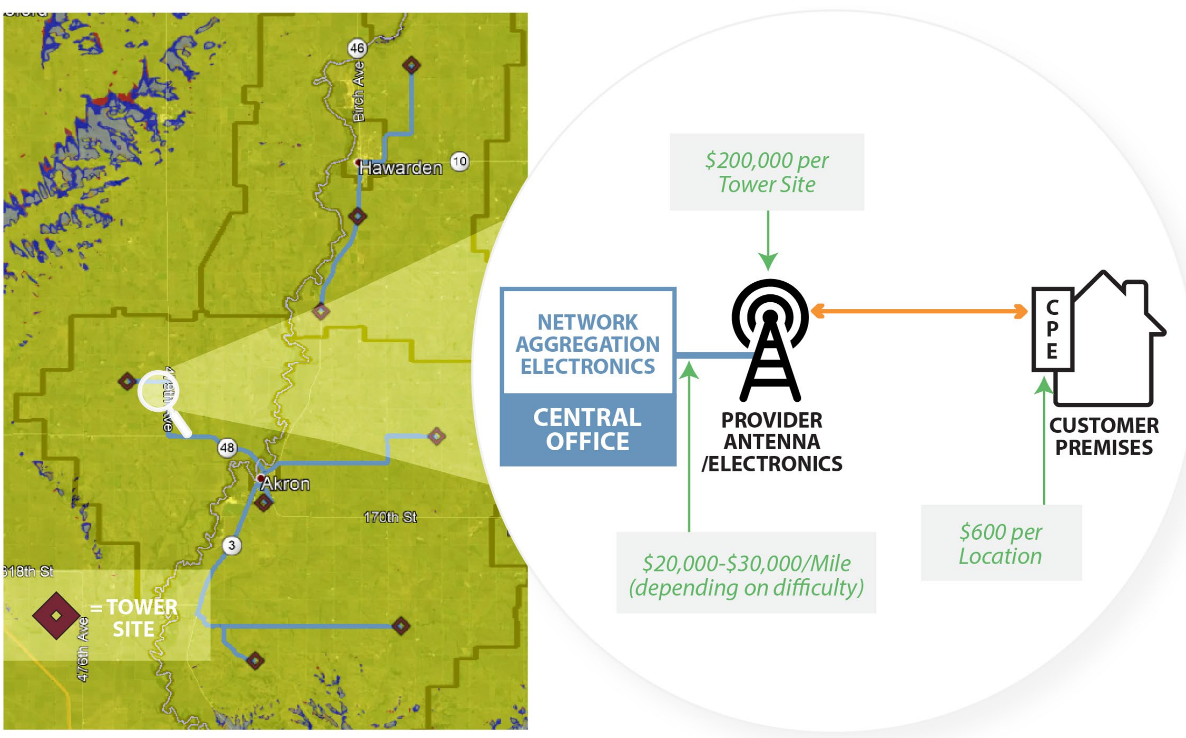

Figure 5: 100/20 Mbps Fixed Wireless Design

Gigabit Wireless Service Design

To serve this same area with gigabit speeds, a total of 170 tower and pole locations would be required as well as fiber to connect some of these towers as show in Figure 6. To achieve 1 Gbps/500 Mbps speeds, this design used mmW band spectrum, since this is the only band that has enough accessible spectrum to provide this speed tier. As discussed previously, the mmW band has limited reach which is one reason why so many more towers are needed as compared to the 100/20 Mbps wireless design, which used mid band spectrum. To serve most rural customers it was found that using E-band spectrum (70/80/90 GHz) in a point-to-point (PtP) configuration was more cost effective than using a mmW point-to-multipoint (PtMP) solution because of the additional distance that can be achieved between the tower and the customer premises. It may be possible, with clear line of sight, for a mmW PtP system to go a few miles depending upon many factors such as terrain, environment, antenna gain, reliability, and desired speed. Because of the narrow beam widths in the mmW band, the cost of these towers (and poles) are more expensive due to their stringent twist and sway tolerances. To ensure the speed and reliability needed in these PtP systems, the distance between the tower and the customer location was normally limited to approximately one mile. A PtMP system using 60 GHz mmW spectrum was used to serve some of the housing clusters, since this proved to be more cost-effective to use, even with the much shorter distances. The design used mmW microwave backhaul instead of fiber when this was more cost-effective, but some tower aggregation points still required fiber connections to meet the network speed and capacity requirements with reasonable oversubscription rates. Even though every attempt was made to minimize costs where possible, the large number of towers (along with other associated costs such as land acquisition) resulted in high deployment costs for this scenario in this case study.

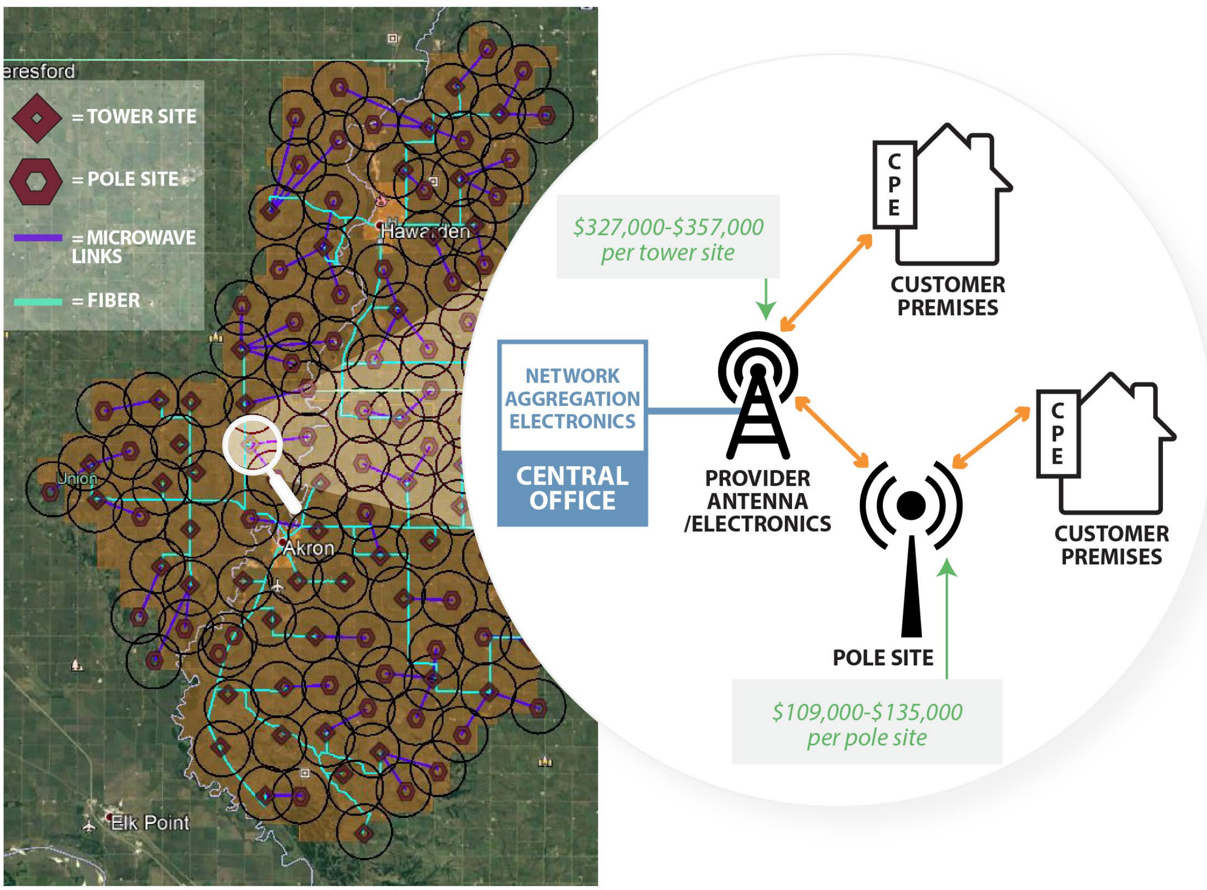

Figure 6: 1 Gbps/500 Mbps Fixed Wireless Design

Hybrid Fiber Coaxial (HFC)

An HFC network design for the rural Hawarden and Akron area would consist of fiber fed nodes with coaxial cable providing the final connection to the customer as shown in Figure 7. In this architecture, the fiber node is the aggregation point and the coax is the last mile technology that was illustrated in the previous Figure 2.

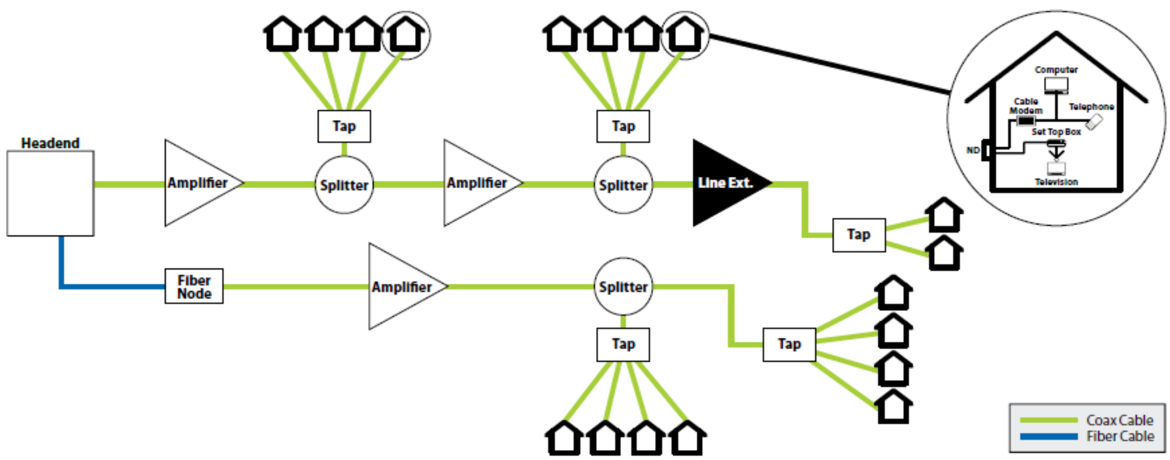

Figure 7: HFC Network

Data Over Cable Service Interface Specification (DOCSIS) 3.1 is the current and most widely deployed technology for broadband over HFC. Due to the attenuation of the electrical signals on the coaxial cables, the signal must be amplified approximately every 1,000 feet along the coax cable. Amplification does, however, degrade the signal quality so HFC systems are typically designed to have five or fewer amplifiers between the fiber node and the customer location in instances where the HFC network is expected to deliver gigabit speeds. Therefore, the HFC design requires a fiber node within approximately a mile or so of each customer.

Since we are assuming a greenfield, new coax cable would need to be constructed from the fiber node to the customer location. Cost of outside plant construction is primarily associated with the labor to place the cable. The number of cable miles of construction for the HFC network is comparable to the FTTP network as will be discussed in the next section. Even considering that the cost of installing a fiber cable is similar to a coaxial cable (for labor and materials) in a greenfield installation, an HFC network is more expensive in a rural environment than the FTTP network.

With the broadband technologies available today, it would not be practical for any provider to deploy an HFC network in a rural greenfield application, since as described further below a network capable of delivering higher performance (FTTP) can be deployed at a lower cost. Some of the reasons a provider would not do HFC in a greenfield application include:

1. The number of miles of outside plant construction is similar between the HFC network and the FTTP network and the labor and materials associated with placing the cable would also be similar between HFC

and FTTP networks. A provider would not install a network that has a similar initial cost yet has lower performance and higher operational expenses.

2. There are additional electronic components in the field that are not needed with a FTTP network. These electronic components increase the cost of the HFC network. For the example area in Iowa, it was estimated that the design would need approximately 180 fiber nodes and 2,000 amplifiers.
3. The fiber nodes and amplifiers in the HFC design introduce potential points of failure in the network that would make it less reliable than a FTTP network that is passive and has none of these field electronics. In addition, each of the fiber nodes require commercial power. Not only does this also introduce reliability concerns, it also increases the operating expense. We estimate that the cost for commercial power alone would be $65,000 per year in the design – almost $2,000,000 over a 30-year period.
4. The broadband speed and performance are far greater on a FTTP network than on an HFC network. Today, FTTP equipment can provide symmetrical 10 Gbps service; in contrast, an HFC network that relies on DOCSIS 3.1 can theoretically provide 10 Gbps downstream and 1 Gbps upstream, but this is shared by all users on the fiber node. Rarely can it achieve its theoretical performance.

For these reasons, HFC was not considered to be a realistic or serious option in this analysis. The only reason a provider would deploy an HFC network would be in a non-greenfield area where they are leveraging an existing coax cable plant; and even then, as existing coax cable reaches the end of its life, it will be replaced by fiber. In short: the HFC networks today will achieve their ultimate goal of moving fiber all the way to the customer premises. The end result will be FTTP, which is the subject of the next section.

Fiber to the Premises (FTTP)

One of Vantage Point's clients recently constructed the rural Hawarden and Akron area shown in Figure 4. Therefore, recent real-world FTTP construction costs are available to utilize for this example. The outside plant design in this project was constructed with a dedicated fiber from each subscriber to the aggregation point.

The aggregation points were central office buildings in Akron and Hawarden. Using this "home run" fiber design allows the use of either PON technologies (GPON, XGS-PON, or NG-PON2) or a dedicated technology (Active Ethernet). This design also allows for the delivery of up to 10 Gbps to each subscriber using equipment readily available today.

In a FTTP system, there are four main cost components: the OLTs, ONTs, mainline fiber, and the drop as shown in the FTTP design in Figure 8. The costs shown are for rural type construction as would be typical for this case study area. The cost estimate assumes construction of the mainline fiber to pass all locations. Drops and electronics are assumed based on a 70% subscriber penetration rate.

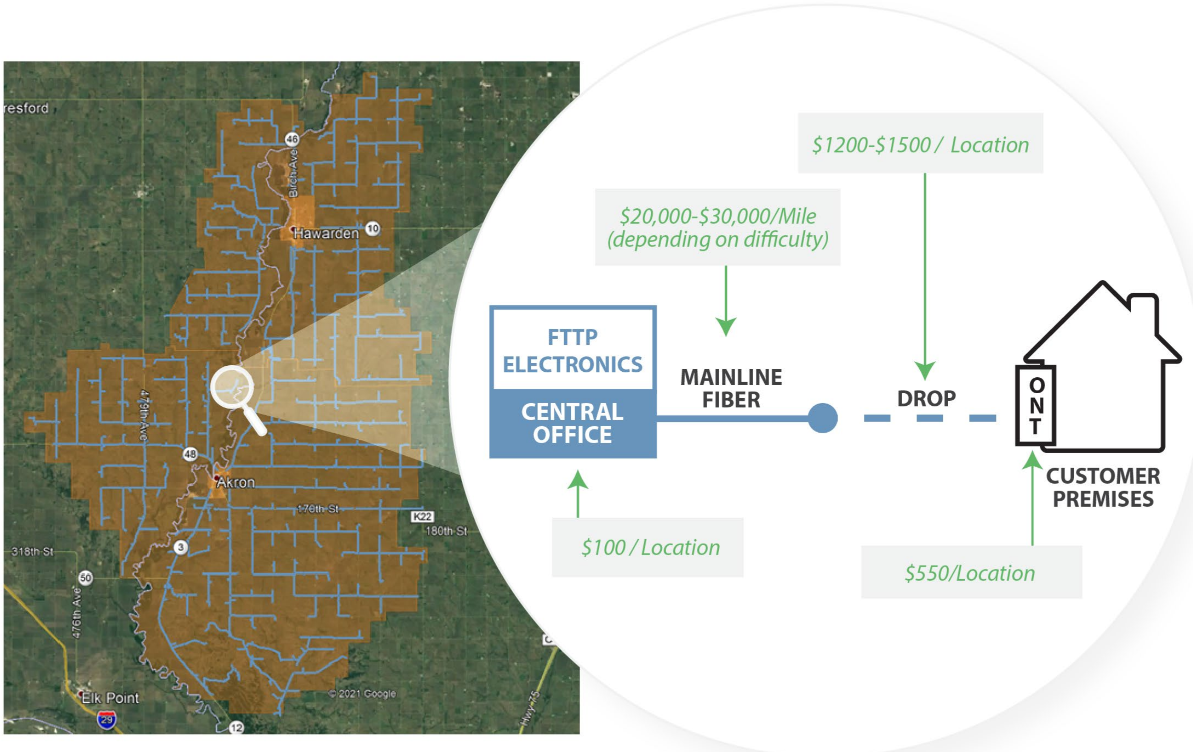

Figure 8: FTTP Design

Cost and Performance Summary

We now shift to analyzing the costs associated with the three basic broadband architectures in the previous section – fixed wireless, HFC, and FTTP – for both initial investment and the expected 30-year investment. For this analysis it was assumed that outside plant cable would last at least 30 years, electronics would last 7 years, on average, and the subscriber base remains stable and a 70% subscriber penetration rate. In addition to estimating the 30-year cost, we also estimate the 30-year performance for each network.

Though obviously no one can predict the future, industry history suggests that there will be far fewer technical barriers for increasing broadband speeds in the future on a wireline network (especially FTTP networks) than on a wireless network. The primary method to increase speeds on a wireless network is to obtain and use more spectrum. All of the remaining spectrum that could be used for broadband purposes, however, is currently being used by others and would need to be repurposed for broadband. The assumptions when estimating future performance can be seen in Table 3.

Technology	30-Year Performance Assumptions
Wireless	We assumed that the FCC would be able to increase the amount of broadband spectrum by 3x (unlikely) and modulation techniques would improve to provide another 2x increase in speed (also unlikely).
FTTP	The amount of broadband speed on fiber is almost unlimited. In 30 years, we will be able to use technologies that today can only be cost effectively used in long-haul transport networks. If we assume 1 Gbps today and a 30% annual growth rate, the speed in 30 years would be more than 2,500 Gbps.

Table 3: Future Performance Assumptions

As shown in Table 4, 100/20 Mbps wireless broadband (using mid band spectrum) has a lower initial cost than does a FTTP network. However, these cost savings mostly disappear over time, since a much larger portion of a wireless network is comprised of electronics which must be replaced every 5-10 years, whereas the FTTP network is made up mostly of fiber optic cable which can last 30 or more years. In the long term, then, the mid band wireless network costs are not significantly different than a FTTP network, but the mid band wireless network delivers far less capability. Referring back to Figure 1, the mid band wireless design provides only half of the average broadband speed experienced by customers today and will fall even farther behind in the coming years. Table 4 estimates that the mid band wireless network in this design may achieve speeds of 600 Mbps at the end of 30 years, yet the average broadband speed in the United States could be 40 Gbps or more if customer demand continues to increase at the current rate.

	Initial Cost & Performance		30-Year Cost & Performance	
	Speed (Mbps)	Capex	Speed (Gbps)	CapEx
Wireless (Mid Band)	100/20	$4.2M	0.6/0.012	$10.2M
Wireless (mmW)	1,000/500	$44.8M	6/3	$78.2M
FTTP	1,000/1,000	$12.6M	2,500/2,500	$14.4M

Table 4: Cost Summary

The vast amount of spectrum available in the mmW band makes this wireless network more comparable to the FTTP network in terms of speed, but it is much more expensive. This is because both the FTTP network and mmW wireless network are mostly made of fiber with the exception of the small "last mile" network section that connects to the customer. In a FTTP network consists mostly of inexpensive fiber drops have been replaced by expensive towers and mmW electronics. The investment in these mmW towers and electronics may make economic sense in a dense urban area where the costs of these can be spread across many customers and where the cost of constructing the fiber drop is much higher. However, in a rural environment, the cost for the mmW network not only had a higher initial cost, but also had a higher 30-year cost because a larger portion of the mmW network investment is once again in electronics which must be replaced more frequently. In addition, the mmW wireless network cannot match the FTTP network from a performance perspective. Thus, unless the propagation of mmW spectrum could be improved considerably to the point where such connections can cover many miles (like fiber) without loss of performance (or signal altogether), FTTP will represent a far more efficient investment in a greenfield scenario. In order to achieve greater distances with mmW wireless, it would come at the sacrifice of either reliability (no longer "carrier grade" service) or performance (can no longer achieve gigabit service).

Figure 9 graphically shows the comparison of the various technologies analyzed in this paper in terms of investment vs performance. Ideally, one would want the technology in the lower righthand corner of this diagram (low cost and high performance). As one can see, FTTP provides high performance at a reasonable cost and very small incremental cost over the life of the network. However, the cost to provide wireless broadband increases more rapidly over time and as the provider increases the speed of broadband provided to their customers.

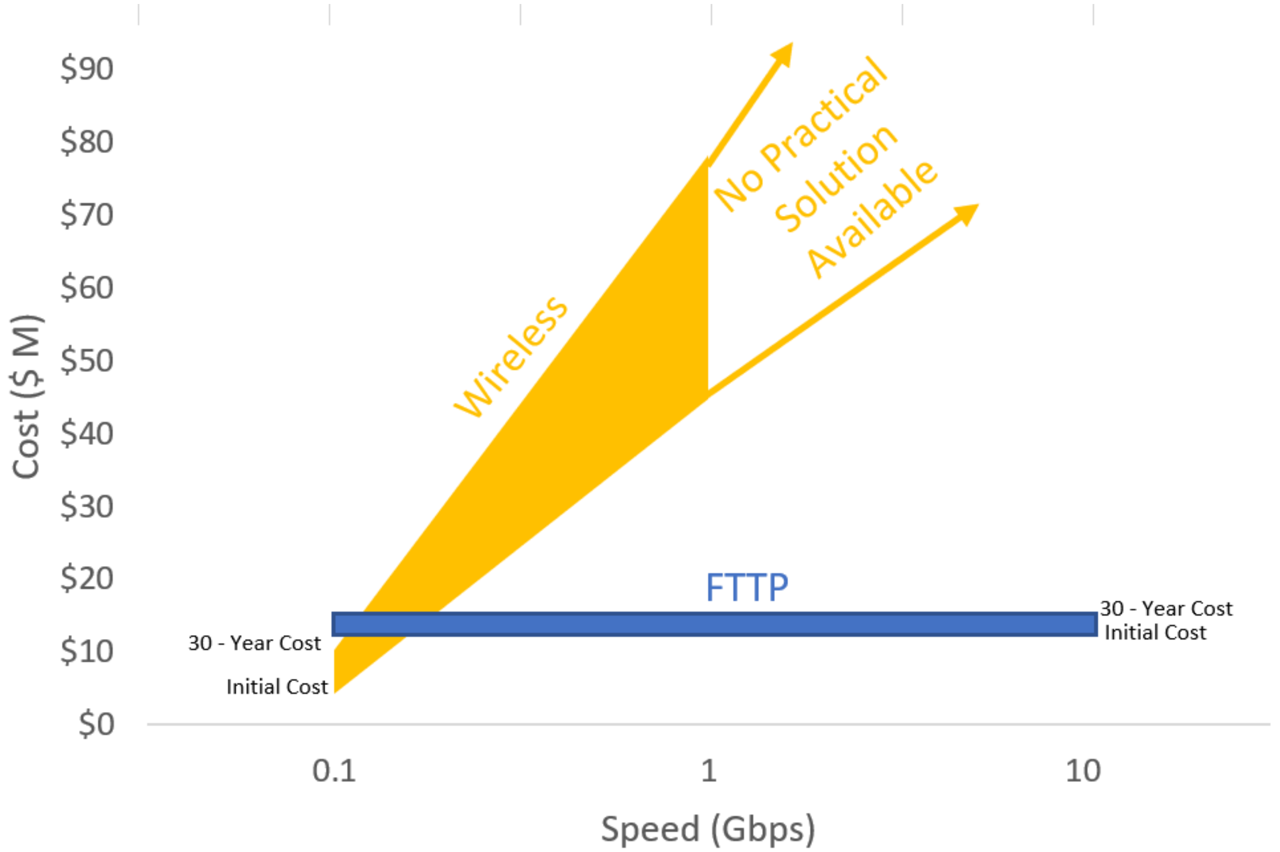

Figure 9: Cost Comparison Summary

Conclusion

Densely populated urban areas provide the economies of scale to allow a variety of broadband technologies – both wireless and wireline – to be economically deployed. In sparsely populated rural areas, however, the trade-offs discussed earlier in this paper must be considered to ultimately determine the best possible balance between performance and the total cost of ownership over time. As shown in the rural case study examined in this paper, the low-cost solution from an initial CapEx perspective does not always reflect the best economic choice in the long-term – especially when it struggles to provide adequate broadband today – much less in the future. It is clear, for example, that HFC networks do not represent an efficient choice for either cost or performance when it comes to deployment of a wireline technology in a greenfield scenario. Moreover, while some – but not all – fixed wireless deployments may require less initial investment than a FTTP deployment, the fixed wireless investment costs become several times greater than the cost of a fiber deployment when designed to provide gigabit speeds and considering the cost over a longer-term timeframe. The fixed wireless deployment will also have greater operational costs over a fiber deployment since each tower requires commercial power and additional spectrum costs which were not considered in this analysis. **This analysis of a greenfield network build therefore confirms that fiber represents the most economical choice for the most capable fixed broadband service on a long-term basis.**

Author Biographies

Larry D. Thompson, PE, CEO

Larry Thompson is a licensed professional engineer and has been designing satellite, wireless, and broadband wireline networks for more than 30 years. Larry received his bachelor's degree in physic from William Jewell College and his bachelor's and master's degrees in Electrical Engineering from the University of Kansas. Prior to founding Vantage Point Solutions in 2002, Larry held several engineering and management positions with TRW's Space and Defense sector, CyberLink Corporation, and Martin Group. Larry is currently the CEO of Vantage Point Solutions, which has over 400 employees and is a national provider of engineering and consulting services. Over the years, he has assisted many wireless and wireline companies successfully manage their technical, regulatory, and financial challenges.

Brian P. Enga, PE, Senior Technology Leader

Brian has been a member of the telecommunications industry for more than 20 years and has Bachelor of Science degree in Electrical Engineering and Engineering Physics from South Dakota State University. Brian, a licensed Professional Engineer in several states, has coordinated many multimillion-dollar broadband network deployments during his career. This has included technical research, plans and specifications development, vendor evaluation, project management, and final inspection. Brian has also managed many loan and grant application submittals for the financing of broadband deployments. This has included both federal and state programs.

Brian Bell, PE, Senior Engineering Staff

Brian Bell has been in the telecom industry since 1999. He is heavily involved in both unlicensed and licensed wireless, FITL, FTTH, standby power and Central Office grounding. A licensed Professional Engineer, he has been responsible for the RF design and evaluations for wireless networks across the suite of current technology standards. His experience includes overseeing the implementation of WiMAX, CDMA and LTE networks. In addition to wireless, he has been responsible for conducting Central Office power and grounding audits, performing ground field measurements, performing soil resistivity measurements, and designing Central Office ground fields based upon soil resistivity measurements.

About Vantage Point

Better Broadband means Better Lives. Vantage Point Solutions, Inc. helps providers bring this promise to life through start-to-FUTURE engineering and consulting solutions tailored to the unique needs of the companies, Cooperatives, and communities we serve.

Combining professional engineering, technical expertise and extensive regulatory knowledge, we design technically advanced and economically viable solutions for sustainable, reliable, future-proofed connectivity. Vantage Point provides a full range of services from financial and regulatory consulting to engineering and cybersecurity to outside plant field collection, mapping, and plant documentation. Our teams work seamlessly to provide peerless service and expertise to our clients, and it is this comprehensive effort that transforms the lives, businesses, and communities we help our clients serve.

Progressive thinking, professional experience, ethical business practices and a legacy of advocacy have established Vantage Point as an industry leader. Headquartered in Mitchell, South Dakota, with six additional offices across the country, Vantage Point serves clients coast-to-coast – from Alaska to Florida, Hawaii to New England. Our boots-on-the-ground staff work side-by-side with client personnel, allowing our services to be continually informed with fresh-from-the-field insights. This broad perspective is invaluable for the 400+ clients we serve.

About the Foundation for Rural Service

The Foundation for Rural Service (FRS), founded in 1994 as the philanthropic arm of NTCA–The Rural Broadband Association and its members, seeks to sustain and enhance the quality of life in rural America by advancing an understanding of rural issues. Through scholarships, grants, and a variety of educational programs, FRS focuses on educating rural youth, encouraging community development, and introducing policymakers and the public to challenges unique to rural communities.

This white paper was made possible by the generous support of the Rural Independent Competitive Alliance (RICA).

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