SHLB
SCHOOLS, HEALTH & LIBRARIES BROADBAND COALITION

February 15, 2018

To Broadband Supporters,

The Schools, Health & Libraries Broadband (SHLB) Coalition is pleased to release the attached paper by CTC Technology & Energy estimating the cost of deploying high-speed, fiber optic broadband to community anchor institutions. The paper supports the idea that deploying high-capacity broadband "to and through" community anchor institutions to the surrounding community can be a cost-effective strategy to solve the digital divide for millions of Americans, especially those in rural areas. The paper makes a number of important findings, such as:

- The cost of deploying fiber to all the remaining anchor institutions (except in Alaska) that do not have high-speed connections can range from $13 billion to $19 billion if done in a coordinated manner over 5 to 7 years. This estimate is based on an extrapolation from the broadband data collected by states and uses a cost model analyzing six different geographic typologies.
- The costs of such deployment could be lower if there is a coordinated national effort to promote broadband deployment. The opposite is also true – the cost could be much higher if broadband is deployed in an ad hoc manner over a very long period of time.
- An open application process that does not pick winners and losers and allows commercial providers (such as incumbent telcos, cable companies, and competitive providers) and non-commercial providers (such as Research and Education Networks and municipal providers) to bid can help to lower the costs of deployment.
- Costs can also be lowered if broadband infrastructure is open to interconnection, so that existing infrastructure could be used rather than building out additional, duplicative infrastructure.
- Ninety-five percent of residential consumers are within the zip code of an anchor institution, an indication that building "to and through" anchor institutions could help bring high-speed broadband to millions of unserved residential and business customers as well.

While this paper focuses on deploying fiber, other technologies such as fixed wireless and unlicensed wireless often provide cost-effective broadband services. A successful rural broadband strategy should also ensure that sufficient TV White Spaces channels are available, allow E-rate and Rural Health Care networks to be extended to the community, streamline permitting processes, and establish coordinated "dig once" policies. Policy-makers should encourage a blend of wireline and wireless services, as determined by local communities.

Anchor institutions, such as schools, libraries, healthcare providers, community colleges, public safety and others, are the cornerstones of American communities. They serve the public interest, not special interests. We encourage policy-makers at the federal, state and local levels to give special recognition to the value that anchor institutions can play as they develop their broadband investment strategies for the future. For more information, please visit www.shlb.org or contact me directly at jwindhausen@shlb.org or by phone at 202-256-9616.

Sincerely,

John Windhausen, Jr.

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A Model for Understanding the Cost to Connect Anchor Institutions with Fiber Optics

Prepared for the Schools, Health & Libraries Broadband (SHLB) Coalition

February 2018

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1. Executive Summary

This report provides a model for understanding the cost to build world-class broadband communications to the community anchor institutions (Anchors) across the United States that are not currently connected with adequate infrastructure.[1] Such an effort would not only bring future-proof, reliable broadband to the Anchors, but would create a potential jumping-off point for closing the digital divide; connecting Anchors would bring middle-mile communications infrastructure to within the ZIP code of roughly 95 percent of the U.S. population—making last-mile deployment more feasible.

The report analyzes the various elements of the cost of extending fiber optics—the technology most commonly used to provide reliable 1 Gbps (and beyond) service—to schools, libraries, hospitals, health care clinics, public safety entities, community colleges, community centers, and other Anchors that do not currently have direct fiber connections.[2]

In brief summary, the model begins by estimating the number of U.S. Anchors that do not currently have fiber connections by extrapolating from data collected by the federal government regarding Anchor locations and by estimating what percentages are currently connected. It divides the country into six standardized geographic typologies from an engineering and network construction standpoint and estimates the average cost to connect a single Anchor within each typology.

The cost estimates include extending fiber to the Anchor from a central office,[3] hub facility, or middle-mile or backbone fiber interconnection point; entering the building; and installing

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[1] "Complete National Dataset – U.S. Community Anchor Institutions," National Broadband Map, Federal Communications Commission, https://www.broadbandmap.gov/data-download (accessed December 26, 2017). This dataset is now housed at the FCC, but it was originally collected by states through the National Telecommunications and Information Administration's (NTIA) State Broadband Initiative program. As defined by NTIA, anchor institutions include "schools and libraries, community colleges and institutions of higher learning, medical and healthcare providers, public safety entities and other community support entities" (https://www2.ntia.doc.gov/files/BTOP_BroadbandMappingFAQs.pdf). The FCC also defines Anchors to "include such entities as schools, libraries, hospitals and other medical providers, public safety entities, institutions of higher education, and community support organizations that facilitate greater use of broadband by vulnerable populations, including low-income, the unemployed, and the aged." (https://www.fcc.gov/news-events/blog/2012/06/01/wcb-cost-model-virtual-workshop-2012-community-anchor-institutions) (accessed December 26, 2017).

[2] While this report focuses on fiber optics as the most commonly used technology to provide reliable 1 Gbps (and beyond) service, we note that fixed wireless providers may, under some circumstances, offer a competitive broadband service to Anchors at a lower capital cost.

[3] The cost estimates include incrementally upgrading optics at the central offices and other interconnection points, but not major upgrades of electronics. Some central offices may have insufficient or outdated network electronics.

premises electronics. The connection point could be owned by an incumbent, by a competitor, or by a non-profit or public broadband provider.

As with any large-scale projection, the model relies on reasonable assumptions and normalizes a range of numbers (e.g., distances, construction costs) that will vary widely in practice. This document clearly describes the assumptions so that the model can be fully understood and, potentially, adjusted over time—as more data become available or as various factors change.

The model also relies on the reasonable assumption that there will be opportunities to leverage existing communications infrastructure to complete this project, such as overlashing fiber to existing aerial strand and cables. It thus assumes that incumbent telecommunications and cable operators, as well as competitors and other network operators such as research and education networks and municipal providers, will be key partners in this effort.

Similarly, the model assumes that construction will be coordinated on a regional or statewide basis in order to ensure maximum efficiency and to avoid the far higher per-unit pricing inherent in small per-facility or local projects. Under these assumptions, **the model suggests that the total cost to connect all unconnected Anchors in the continental United States and Hawaii will be between $13 billion and $19 billion**.

The model also suggests that if adequate funding is appropriated and a major, national, coordinated effort is undertaken in coordination with state and regional authorities, **savings of up to 50 percent are possible.**

If construction takes place over an extended period of time and in an ad hoc fashion, total estimated construction costs could multiply many times.

1.1 Connecting Anchors

The model analyzes the costs for connecting Anchors in the continental United States and Hawaii; it excludes Alaska.[4] We created high and low estimates, bounding the main areas of uncertainty, for each standardized typology (Table 1).

The average cost to connect Anchors with last-mile fiber—including constructing the last-mile fiber, bringing the fiber into the building, and acquiring and activating the network electronics—

[4] Alaska is not included because it cannot be categorized accurately in our analysis without state-specific information that is not publicly available. Because many separate Alaskan rural areas are not directly connected by road or fiber, central office connectivity is different case-by-case, and using our model will likely underestimate the cost and challenges of connectivity. We recommend a focused study in which the presence of incumbent Alaskan carrier fiber and capacity is reviewed, and Alaska is separated into 1) areas with fiber-connected central offices, 2) areas where central offices and Anchors can affordably construct fiber, and 3) areas where satellite communications is the best option.

ranges across typologies, from $34,000 per an Anchor for connecting a large number of Anchors in a metropolitan area to $151,000 per Anchor for connecting a large number of Anchors in a desert area.

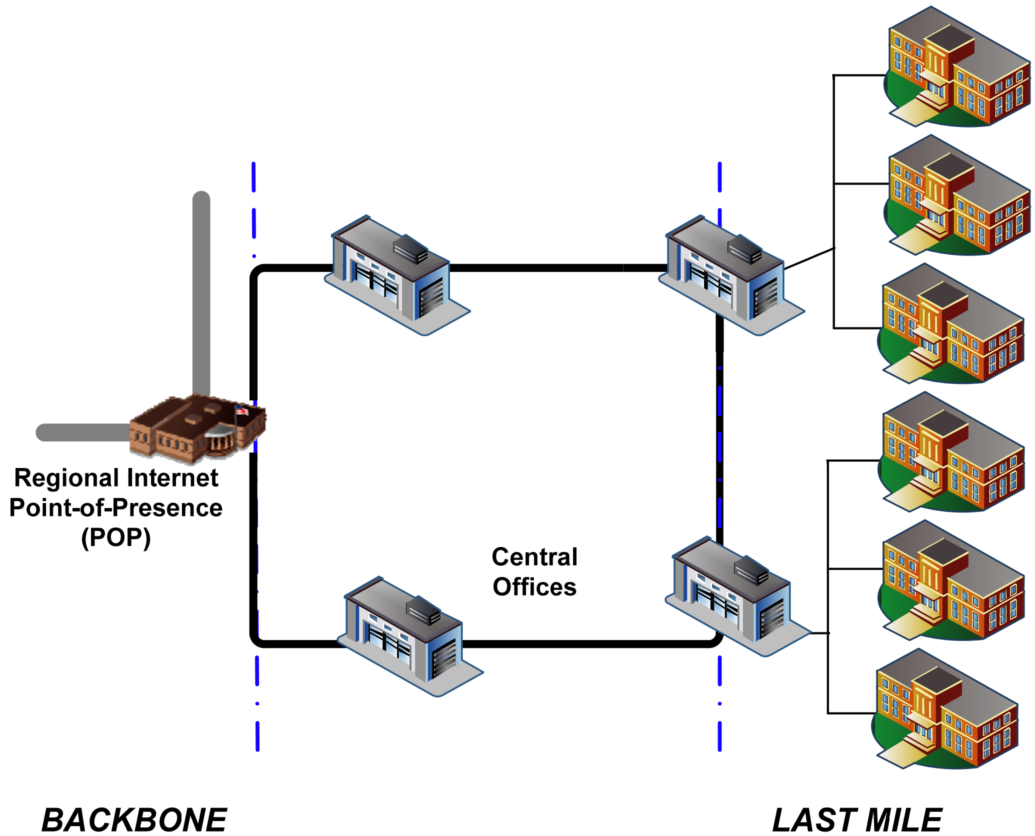
Table 1: Average Cost to Connect Anchors by Typology—Low and High Models

	Dense Metro	Intermediate Metro	Low Density Metro	Rural Eastern Mountain	Rural Western	Desert	Plains	Rural Eastern
Low	$34,000	$47,000	$82,000	$51,000	$56,000	$97,000	$66,000	$75,000
High	$47,000	$71,000	$126,000	$76,000	$81,000	$151,000	$97,000	$112,000

In metropolitan areas, Anchors can typically access fiber closer than the central office. Cable TV operators use a hybrid fiber-coaxial architecture that brings fiber optics to a node within a half-mile to a mile of any point in the cable system, depending on the density of the area. Telephone companies may have fiber in neighborhood cabinets to support enhanced digital subscriber line (DSL) service. Fiber-to-the-premises (FTTP) exists in some areas and brings fiber to each served neighborhood (but frequently not to institutional or commercial areas). Depending on the density of the metropolitan area, we assume that fiber exists within 0.4 to 2.5 miles of each Anchor.

The model estimates the cost of constructing fiber from Anchors in rural areas to central offices or other connection sites, which typically have a robust connection back to a regional internet point-of-presence (Figure 1). The estimated distances required to connect Anchors in various areas are discussed in Section 4.

Figure 1: Backbone and Last-Mile Fiber in Rural Areas



Because almost all Anchors are connected by telephone or cable infrastructure, we assume it is technically possible to use existing infrastructure in many locations to assist in placing fiber to the Anchors. As discussed in Section 3, we assume that half the fiber required to connect Anchors is overlashed to existing aerial strand or placed in existing underground conduit.

1.2 Summary of Methodology

Our methodology included four primary steps:

1. Drawing on data from the U.S. Census Bureau, the U.S. Environmental Protection Agency (EPA), and the U.S. Geographic Names Information System (GNIS), we divided the country into six standardized geographical typologies from an engineering and network construction standpoint (see Figure 2, below). These typologies are:

    a. Metro (Dense, Intermediate, and Low-Density)
    b. Desert
    c. Plains
    d. Rural Western
    e. Rural Eastern Mountain
    f. Rural Eastern

2. Based on CTC's field experience with broadband throughout the United States, as well as consultation with state and local broadband planners, and members of SHLB's leadership, we developed estimates of the percentage of U.S. Anchors in the different typologies that are not yet fiber connected.

3. We estimated the average cost to connect an Anchor within each typology, including costs for:

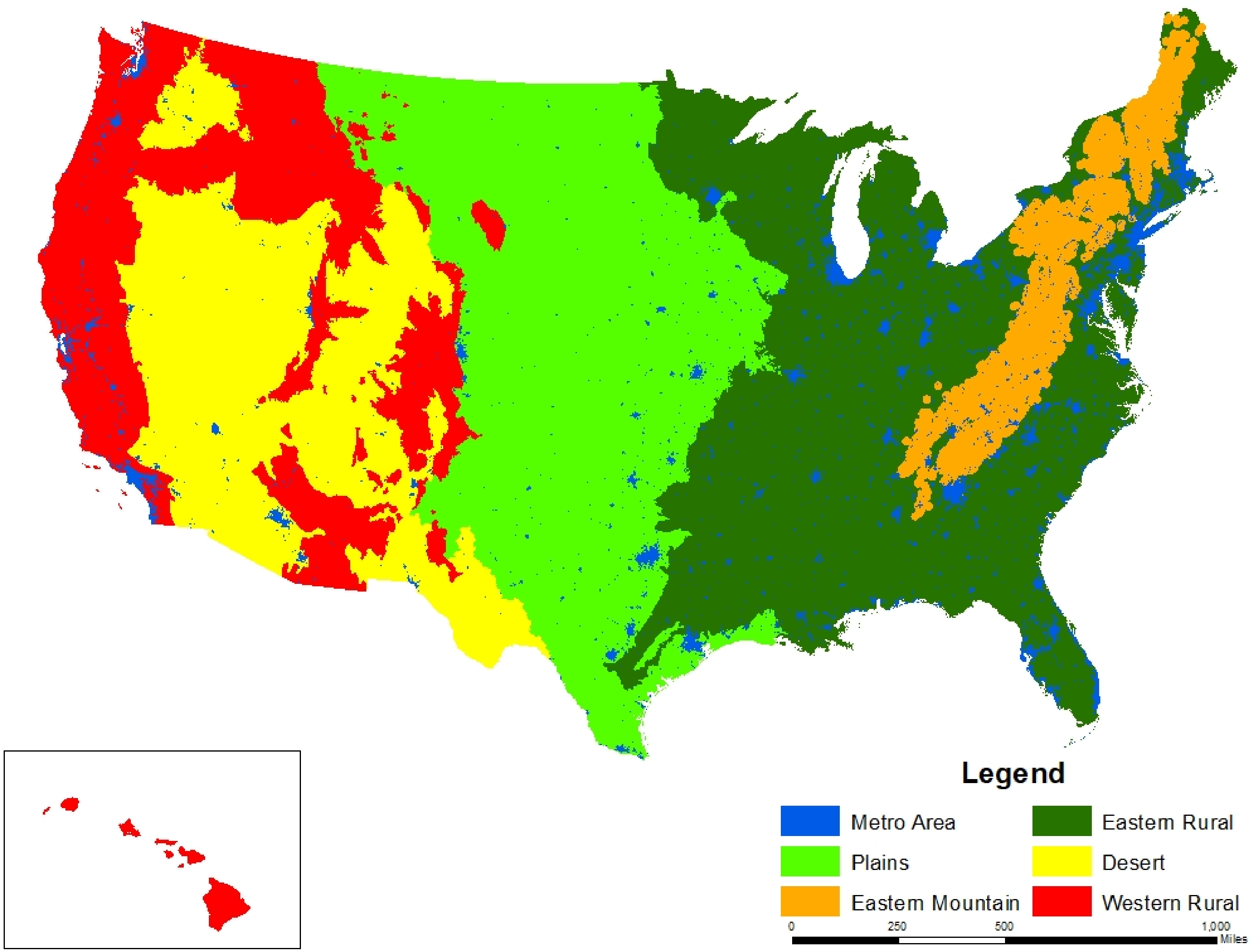
    a. Last-mile fiber construction (labor and materials per mile)
    b. Building entry
    c. Network electronics

    We completed this step twice in rural areas—once for a low estimate, then again with key assumptions varied to identify a high estimate. The low estimate assumes that Anchors without fiber are equally likely to be close to a central office or other connection point as an Anchor with fiber. The high estimate assumes that Anchors without fiber are more likely to be distant from the central office or other connection point. We also estimated the cost of fiber construction between connection points that do not have fiber and an adjacent central office or another location for internet access. These costs are described in Sections 3 through 5.

4. Based on the likely percentage of Anchors that are not yet fiber connected in each typology, the order-of-magnitude cost per mile to construct fiber in the different typologies, and the Anchors identified in the National Telecommunications and Information Administration's (NTIA) anchor dataset[5] in each typology, we calculated high-level estimates of the total cost of connecting the facilities.

[5] The Anchor dataset, available in GIS format, is based on data voluntarily submitted by individual states to NTIA. The dataset was last updated in 2014. *See:* U.S. Department of Commerce, National Telecommunications and Information Administration, State Broadband Initiative (CSV format June 30, 2014).

Figure 2: Standardized Typologies



NTIA listed seven categories when it solicited Anchor information from the states: schools, libraries, medical/healthcare centers, public safety facilities, universities and postsecondary schools, other community support governmental facilities, and other community support non-governmental facilities. However, while NTIA provided the Anchor categories, it did not require a standardized data submittal by the states.

The states interpreted these categories independently; some provided data that reflect their individual circumstances. For example, Utah reported Anchors that primarily deal with natural resources such as guard stations, ranger stations, and research centers. Hawaii's list of Anchors seems to include locations with public Wi-Fi access, such as coffee shops, restaurants, and hotels.

Because of these variations in data (e.g., states used varying definitions of Anchors and submitted varying amounts of detail on their Anchors), we made a range of assumptions and extrapolated from the data.

Working with a representative subset of NTIA's dataset, we extrapolated construction numbers based on population to establish a normalized model for the number of Anchors across the country.

We developed sample designs in GIS to determine the average amount of last-mile fiber required to serve the Anchors from the nearest phone or cable company central office (which we assumed to be fiber-connected) or another middle-mile or backbone fiber interconnection point. The model assumes that Anchors cluster around one another in many areas.

Importantly, the sample designs assume that a fiber construction project would connect all of the Anchors in an area at once, in a single effort. This type of coordination is essential to containing costs. For example, a sample design that connects 20 Anchors in relatively close proximity might cost $10 million, or an average of $500,000 per Anchor. If construction to those 20 Anchors were not coordinated, it could cost millions of dollars each to reach the most distant Anchors in the same sample design—and the total cost of connecting all of the Anchors in separate projects would be considerably more than $10 million.

We selected sample designs in areas that reflect the typologies as a whole, then averaged the fiber mileage required in each sample design. We created a low-end cost estimate by subtracting from the average 25 percent of the last-mile fiber construction. The high-end cost estimate was created by adding 25 percent of the last-mile fiber construction required in the average.

1.3 Estimate for How Many Anchors Require Connections

Based on CTC's field experience with broadband throughout the United States, as well as consultation with state and local broadband planners, and members of SHLB leadership, we developed estimates of the percentage of U.S. Anchors in the different geographic typologies that are not yet connected over robust and scalable broadband connections (Table 2).

Table 2: Estimate of Anchors That Are Not Currently Connected by Fiber

Typology	Estimated Percentage Connected	Estimated Percentage Unconnected
Dense Metro	85 percent	15 percent
Intermediate Metro	65 percent	35 percent
Low-Density Metro	50 percent	50 percent
Desert	40 percent	60 percent
Plains	40 percent	60 percent
Rural Western	30 percent	70 percent
Rural Eastern Mountain	35 percent	65 percent
Rural Eastern	40 percent	60 percent

Using these percentages, we developed estimates of the number of U.S. Anchors that currently are directly connected over fiber and the number that lack fiber connections.

1.4 Total Capital Cost for Building Fiber to Anchors That Require Connections

We estimate the total cost to connect all unconnected Anchors in the continental United States and Hawaii to be between $13 billion and $19 billion, if the Anchors are connected in incremental fashion without the benefit of the efficiencies realized by a single, coordinated, multi-year effort. If buildout happens in an ad hoc, entirely uncoordinated fashion, total costs could be considerably higher.

Those costs could potentially be reduced through the application of a number of proven best practices:

1. *Open, competitive bid processes for awarding broadband funding:* Whether on a local, state, or national level, an open and competitive procurement process that does not favor any class or type of recipient will result in the most cost-effective outcome for deployment of infrastructure in a given area. Ideally, competition should be part of every part of the process with fully open eligibility to participate. Limiting eligibility to a select group of providers or deployers will almost certainly increase aggregate costs dramatically.

2. *Open interconnection policies:* Deploying broadband infrastructure in an open-interconnection environment will result in the lowest aggregate cost because network deployers can access some existing infrastructure rather than constructing all new assets to reach the Anchor. The converse is also true: If existing providers do not open their networks to interconnection, it will be more expensive to connect Anchors. This report assumes the availability of interconnection throughout the country as a means of ensuring cost-effectiveness.

3. *Coordinated construction on a local level:* Building communications infrastructure to individual or few Anchors will inevitably lead to inefficiencies on a local or regional level. In contrast, building efficiently-routed infrastructure that connects all or many Anchors in an area or region will greatly reduce the average cost to connect each Anchor.

4. *Coordinated national effort:* Expanding on the benefits of coordinated local and regional construction, a coordinated national broadband deployment effort would greatly lower the cost to connect Anchors by realizing efficiencies and enabling staging of construction. In the event that significant coordination and planning are undertaken, savings of up to 50 percent are possible; in contrast, absent planning and coordination, the total cost to connect Anchors throughout the country could be many times what our cost estimate here suggests.

   Coordination would also allow for labor and material supply to grow to meet the demand of such a significant effort—thus reducing the risk that per-unit prices will greatly increase in the event that many states, regions, or other entities all endeavor at one time to secure contractors, materials, and employees. A staged national buildout planned for five to seven years would likely be short enough to enable efficiencies and maximize benefits while not causing labor and material costs to spike as different regions of the country compete for resources.

Because this model depends on many Anchors accessing robust internet connections at central connection locations, we also developed an order-of-magnitude estimate of $500 million for the fiber construction that may be necessary to connect central offices and other connection points that currently do not have fiber to adjacent central offices or other locations for internet access (Section 6).

While operating expenses are outside the scope of this report, we note that ongoing fiber maintenance costs typically range between 1 and 2 percent of outside plant capital construction cost.

2. Standardized Geographic Typologies

Our cost model addresses the diversity of existing physical plant and construction characteristics in the United States by dividing the country into six standardized geographic typologies that—from an engineering and networking standpoint—reflect factors such as labor costs, population density, distances between Anchors, and the difficulty of building fiber in various terrains.[6] In our experience, construction costs are more similar within these categories than they are within a particular state, because a state is often a mixture of these typologies.

Drawing on data from the U.S. Census Bureau, the U.S. Environmental Protection Agency (EPA), and the U.S. Geographic Names Information System (GNIS), we defined the typologies as:

a. Metro (Dense, Intermediate, and Low-Density)
b. Desert
c. Plains
d. Rural Western
e. Rural Eastern Mountain
f. Rural Eastern

We describe the typologies below. In Section 3 we define the construction categories that will be required in the different typologies, and in Section 4 we list the average amount of fiber construction required in each.

2.1 Metro Areas (Dense, Intermediate, and Low-Density)

We defined metropolitan areas to align with U.S. Census Bureau-defined urban areas.[7] Using Esri ArcGIS software, we imported the Census dataset and applied it as a filter to the map of the United States (including Hawaii, but excluding Alaska) to identify all urban areas across the

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[6] Alaska was not included in the model because it cannot be categorized accurately in our analysis without state-specific information that is not publicly available. Because many separate Alaskan rural areas are not directly connected by road or fiber, central office connectivity is different case-by-case, and using our model will likely underestimate the cost and challenges of connectivity. We recommend a focused study in which the presence of incumbent Alaskan carrier fiber and capacity is reviewed, and Alaska is separated into 1) areas with fiber-connected central offices, 2) areas where central offices and Anchors can affordably construct fiber, and 3) areas where satellite communications is the best option. Hawaii is included in the model, divided between two typologies: Dense Metro (assuming that Anchors are clustered together in population centers) and Rural Western (assuming that, while most Anchors in the state are on the coasts, there is construction complexity in the rural areas related to the state's soil and rock composition).

[7] "Cartographic Boundary Shapefiles - Urban Areas: 2013," U.S. Census Bureau, https://www.census.gov/geo/maps-data/data/cbf/cbf_ua.html (accessed December 26, 2017). *See also:* "2010 Census Urban and Rural Classification and Urban Area," U.S. Census Bureau, https://www.census.gov/geo/reference/ua/urban-rural-2010.html (accessed December 26, 2017).

country. This category includes a range of metropolitan environments, from low to high population density.

The distinction between these three categories of metro areas is the average population density. While in reality each metropolitan area will have a range of densities spanning from the central business districts to the suburbs, our model averages that range within each category.

Aside from high population densities relative to rural typologies, one distinguishing factor among metro areas is the presence of both telephone and cable TV service. In a cable TV or advanced DSL system, operators typically have fiber deep into neighborhoods, so connecting Anchors will not require extensive extended fiber construction.

Labor costs for fiber construction are higher in Metro areas in our experience, increasing per-unit construction costs relative to rural areas.

The average fiber distance will increase with the average density of the metro areas. We take into account the fact that often the reason an Anchor is not yet fiber connected is that it is not close to existing infrastructure and the built-up areas of the suburb.

In the model presented here, a Dense Metro area has an average population density of more than 2,500 residents per square mile. Examples include New York City, Los Angeles, and Dallas. A Dense Metro area has proportionately more Anchors in proximity to fiber, because cable TV and telephone company networks are more fiber-dense to accommodate capacity needs. However, construction costs are higher, especially for underground construction, because of a relatively higher percentage of areas where concrete needs to be restored, and because of higher density and complexity of existing utilities.

Intermediate Metro areas have average population densities between 1,670 and 2,500 residents per square mile. Examples include Dayton, Oh., Memphis, Tenn., and Reno, Nev. Relative to a Dense Metro Area, there will be lower fiber density and therefore more instances where longer distances are needed to connect an Anchor to fiber. However, the lower density often corresponds to relatively less costly and less complex underground construction, as well as opportunities to construct fiber to avoid congested areas and areas with high restoration costs.

Low-Density Metro areas in our model have average population densities between 363 and 1,669 residents per square mile. Examples include Bristol, Va./Tenn., Sturgis, Mich., and Springfield, Va. Relative to other metro areas, there will be lower fiber density and therefore more instances where longer distances are needed to connect an Anchor to fiber. Furthermore, there will be a relatively higher percentage of low-density suburban areas with longer distances needed to connect Anchors. As with Intermediate Metro areas, Low-Density Metro Areas will have relatively less costly and less complex underground construction, as well as opportunities to construct fiber to avoid congested areas and areas with high restoration costs.

Specific requirements will depend on the existing plant and utility poles in a given community, including both the routing and amount of existing fiber. Based on our experience in fiber buildout in urban and suburban areas, there exists sufficient fiber to central offices.

2.2 Desert

The Desert typology aligns with the EPA's level I ecoregion classifications.[8] We imported the EPA's dataset into Esri and applied it as a second filter, identifying all non-metro desert areas. The Desert typology has the lowest population density of all the categories. Sample areas include rural Nevada, Arizona, Utah, New Mexico (exclusive of mountainous areas), and western Texas.

Compared to mountainous regions, construction is cheaper in the desert. The low complexity of restoration and existing utilities makes construction inexpensive on a per-mile basis. However, Anchors are the most widely dispersed of any of the typologies, and therefore total costs per Anchor are high.

2.3 Plains

The Plains typology is defined in our model, per the EPA's level I ecoregion classifications, as the large rural areas west of the Mississippi River that are not desert, mountainous, hilly, or highly wooded. We imported the EPA's dataset into Esri and applied it as a third filter, excluding all metro and desert areas.

The Plains have a higher population density than the Desert typology, but the area is less dense than the Rural Eastern typology.

2.4 Rural Western

The Rural Western category covers the rural areas of the western states, exclusive of the Metro, Desert, and Plains areas. These are the areas that remain after applying the previous three filters—including the Pacific coastal region, the western forests, the Rocky Mountains, the Sierra Nevada Mountains, and rural parts of the California Central Valley.

The Rural Western category is more rugged than the Plains, and thus construction there will be more difficult. This category has a higher population density than the Desert but a much lower population density than the Rural Eastern typology.

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[8] "Ecoregions of North America: Level I Ecoregions," U.S. Environmental Protection Agency, https://www.epa.gov/eco-research/ecoregions-north-america (accessed December 26, 2017).

2.5 Rural Eastern Mountain

This category encompasses areas east of the Plains that include or are within 10 miles of a mountain peak 500 meters or higher. Using Esri software, we imported those data from the U.S. Geographic Names Information System and applied those parameters as a filter to the portions of the contiguous United States remaining after identifying Metro, Desert, Plains, and Rural Western typologies. This category includes the Appalachian Mountain region and extends from Alabama to Maine, centered around West Virginia. The region is denser than the Rural Western regions, with more population and more Anchors.

However, the Rural Eastern Mountain typology is a particularly challenging and expensive area for building fiber because of rocky soil and windy roads.

2.6 Rural Eastern

In our model, the Rural Eastern typology encompasses areas east of the Plains, excluding the areas defined as Rural Eastern Mountain and Metro. It includes most of the non-Metro and non-mountain South and all of the Midwest east of the Plains, as well as many rural portions of the northeast. This typology is defined by default as the areas remaining after applying all other filters.

This typology is more densely populated than the Rural Western areas. Based on our experience with fiber design and construction projects in this region, we estimate an even split between aerial and underground construction.

3. Construction Cost Assumptions

The cost of constructing a mile of fiber in two different locations—even locations that are quite close to each other—could differ significantly, given variables such as topography, existing infrastructure, and regional labor costs. To normalize and average the potential cost in a given area on a per-mile or a per-Anchor basis, our model makes some basic assumptions based on our experience with network deployments in rural, urban, and suburban communities nationwide.

Based on our expertise in cable physical plant construction in each of the typologies, we worked through a full range of objective and subjective factors to reasonably account for variations in per-unit construction cost, population density, and aerial and underground construction.

The primary factors and assumptions underlying our construction cost analysis include the following:

1. *The location of unserved Anchors*—we developed two different models (low and high), which make different assumptions about where unserved Anchors are located. The Low model assumes that unserved Anchors are distributed evenly among all Anchors; the High model assumes that unserved Anchors are the most distant Anchors from the central office or other interconnection point. In our experience, the most outlying facilities, in terms of location relative to population density and central offices, are less likely to be fiber connected.

2. *The distribution of Anchors*—within each of the six identified typologies (see Section 2) we analyzed sample regions and calculated average distances of fiber construction needed to connect unserved Anchors.

3. *The cost of construction (labor and materials)*—based on recent large-scale projects,[9] we assumed there will be different labor rates for urban/suburban and rural areas, and that there will be a single average drop installation cost for each Anchor connected.

4. *The scope of the construction projects*—we assume the construction of fiber to Anchors will be a large-scale, coordinated effort with large-volume contracts, highly centralized project management, and will leverage all possible economies of scale in labor and materials. The cost of many small projects would be considerably higher, because there would be many separate workforce mobilizations, significant procurement overhead,

[9] These numbers were based on our experience designing networks in rural, urban, and suburban communities; our experience designing fiber connections to Anchors for three decades; and our reasonable assumptions about the cost of extended last-mile fiber construction in different kinds of typologies.

higher per-unit costs, and more delay coordinating with utility pole owners, right-of-way owners, and existing utilities.

5. *The percentage of aerial and underground construction, and the percentage of new versus overlash and existing conduit*—we based these estimates on our network engineering and construction experience in a range of typologies:

    a. We assumed that the percentage of aerial and underground construction will vary by typology.

    b. We assumed that new fiber will be overlashed to existing strand for half of all aerial construction.

    c. We assumed that existing conduit will be used for half of all underground construction.

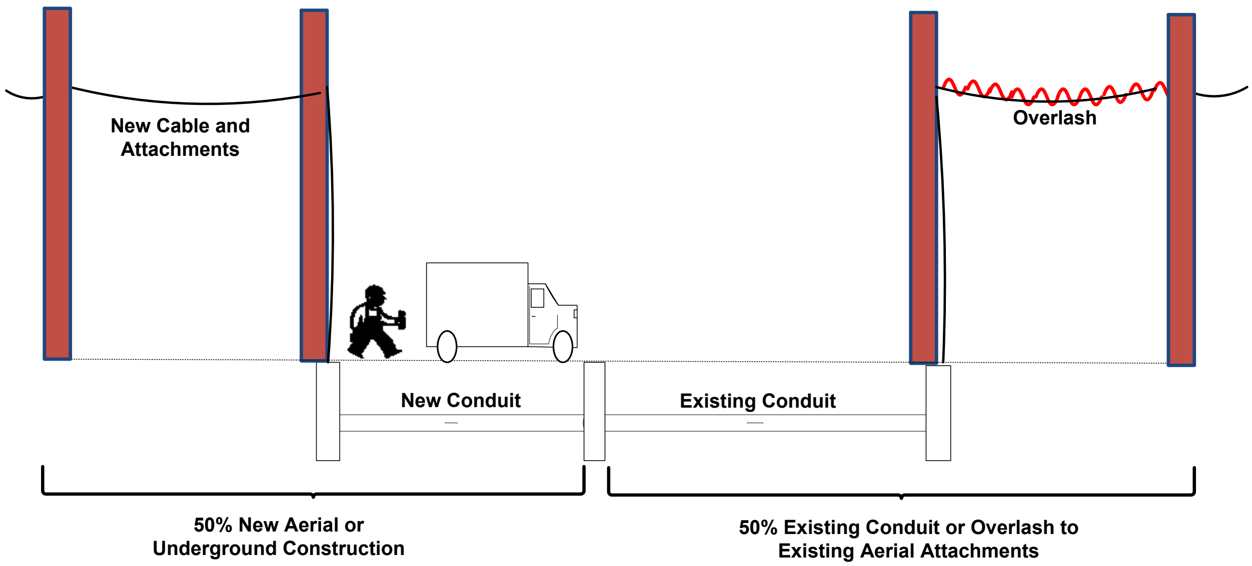
    d. We assumed that new construction will be required for the remaining half of both aerial and underground construction.

6. *The ability to harness existing networks*—we assumed that the last-mile construction to each Anchor originated at an existing network asset. These assets might include central offices, hubs, middle-mile fiber, or backbone fiber.

7. *The construction of fiber to all Anchors*—the cost per Anchor is based on building fiber to all Anchors. This approach factors in the inherent clustering of Anchors around population areas, even in rural locations. Importantly, the sample designs also assume that all of the Anchors in an area will be connected to fiber at once, in a single construction project.

Figure 3 below illustrates a single connection that is evenly split between new construction (50 percent) and the use of existing conduit and strand (50 percent). The model also takes into account situations where an incumbent provider is not willing or able to participate, or where earlier design choices (e.g., previous construction of self-supporting communications cable unable to support overlash, existing conduit full or damaged) preclude the use of existing infrastructure.

Figure 3: Breakdown of Fiber Construction Between New and Existing Infrastructure



Based on these assumptions and our work and experience in this field, we developed nine construction categories that reflect the type of existing and required infrastructure in various settings. *These are used as building blocks in the cost model, in that construction in each standard typology is composed of different mixtures of these construction categories, as listed in Table 3* below.

The construction categories are:

1. Aerial—new
2. Metro aerial—overlash
3. Rural aerial—overlash
4. Underground—new
5. Metro underground—dense urban—new
6. Metro underground—existing conduit
7. Rural underground—existing conduit
8. Mountain underground—new
9. Desert/plains underground—new

We list average per-mile costs and methodology for each of the construction categories in the sections below.

Table 3: Distribution of Construction Categories Across Typologies

Construction Category	Dense Metro	Intermediate Metro	Low-Density Metro	Desert	Plains	Rural Western	Rural Eastern Mountain	Rural Eastern
Aerial—New	25%	25%	25%	37.5%	37.5%	45%	45%	25%
Metro—Aerial Overlash	25%	25%	25%	–	–	–	–	–
Rural—Aerial Overlash	–	–	–	37.5%	37.5%	45%	45%	25%
Underground—New	22.5%	25%	25%			4.5%	4.5%	25%
Metro Underground—Dense Urban—New	2.5%	–	–	–	–	–	–	–
Metro Underground—Existing Conduit	25%	25%	25%	–	–	–	–	–
Rural Underground—Existing Conduit	–	–	–	–	–	5%	5%	25%
Mountain Underground—New	–	–	–	–	–	0.5%	0.5%	–
Desert/Plains Underground—New	–	–	–	25%	25%	–	–	–

3.1 Aerial—New

Based on our experience on a wide range of metro area and rural projects, and on the unit contractor costs we have seen for large-scale projects, we developed an estimate over a large ensemble of aerial construction projects.

This construction category is for construction of new fiber on aerial strand. This construction category encompasses all tasks including design, finding and creating space on poles (sometimes requiring moving existing utilities, also known as make ready), placing attachments on poles, placing strand, and lashing fiber cable to strand. Make ready costs (inclusive of make ready engineering) may vary widely based on the local environment and the existing utilities.

The table below illustrates an average cost for new aerial construction—roughly $51,000 per mile. There will be variation in cost for a given mile depending on the quality and capacity of the existing pole line, the quality of the poles, and cooperation with the existing utilities. We have found significant variations within all of the typologies and present this number as an average.

Table 4: New Aerial Construction Cost

Labor	**Price**		**Quantity**	**Cost**
Design	$300.00	per mile	1.00	$300.00
Place cable	$2.60	per foot	5280	$13,728.00
Splicing	$30.00	per splice	6	$180.00
QC	$1,420.80	lot	1	$710.40
TOTAL LABOR				$14,918.40
Material				
12 count Fiber (Includes 15% slack)	$0.40	per foot	6072	$2,428.80
Strand Wire	$0.21	per foot	5280	$1,108.80
Splice Cases	$350.00	per case	1	$350.00
Snowshoes (3 per mile)	$95.00	per pair	3	$285.00
Tax and freight		lot	1	$417.26
TOTAL MATERIAL				$4,589.86
Material				
Aerial Make Ready Costs	$6.00	per foot	5280	$31,680.00
TOTAL COST PER MILE				**$51,188.26**

3.2 Metro—Aerial Overlash

Overlash is the lashing of new fiber optic cable to existing strand and cables. If overlash is possible, it is significantly cheaper than placement of new cables, because it does not require placement of new strand, reduces the amount of design, and does not require a new attachment to poles or space on the poles.

Overlash is only possible if another existing communications attachment can be lashed. This requires the cooperation of the existing communications provider. It cannot be done if the existing cable is already too heavily loaded, or if the communications provider used self-supporting cable. Typically, overlash is limited to additional cables belonging to the provider being lashed, so our assumption of overlash assumes that an incumbent provider is either providing this portion of the infrastructure or is a key partner in the initiative.

Based on actual unit contractor costs for large-scale projects in many urban and suburban environments nationwide, we have estimated the cost for aerial overlash at about $15,000 per mile on routes where the fiber operator has existing fiber, copper or coaxial cable in place.

Table 5: Metro Aerial Overlash Construction Cost

Labor	**Price**		**Quantity**	**Cost**
Design	$300.00	per mile	1.00	$300.00
Place cable	$2.00	per foot	5280	$10,560.00
Splicing	$30.00	per splice	6	$180.00
QC	$1,104.00	lot	1	$552.00
TOTAL LABOR				$11,592.00
Material				
12 count Fiber (Includes 15% slack)	$0.40	per foot	6072	$2,428.80
Splice Cases	$350.00	per case	1	$350.00
Snowshoes (3 per mile)	$95.00	per pair	3	$285.00
Tax and freight		lot	1	$306.38
TOTAL MATERIAL				$3,370.18
TOTAL COST PER MILE				**$14,962.18**

3.3 Rural—Aerial Overlash

The roughly $12,000 per mile cost for aerial overlash is an average over a wide range of rural areas. It is cheaper than Metro area overlash because of lower labor costs. This construction approach is feasible where the fiber operator or a partner has existing communications cable in place; in a rural environment this is typically overlash on telephone company infrastructure.

Table 6: Rural Aerial Overlash Construction Cost

Labor	**Price**		**Quantity**	**Cost**
Design	$300.00	per mile	1.00	$300.00
Place cable	$1.50	per foot	5280	$7,920.00
Splicing	$30.00	per splice	6	$180.00
QC	$840.00	lot	1	$420.00
TOTAL LABOR				$8,820.00
Material				
12 count Fiber (Includes 15% slack)	$0.40	per foot	6072	$2,428.80
Splice Cases	$350.00	per case	1	$350.00
Snowshoes (3 per mile)	$95.00	per pair	3	$285.00
Tax and freight		lot	1	$306.38
TOTAL MATERIAL				$3,370.18
TOTAL COST PER MILE				**$12,190.18**

3.4 Underground—New

Based on unit contractor costs for large-scale projects, we estimate the cost for new underground construction at $86,000 per mile. This cost assumes that most construction is directional boring, with a minimal amount of hand-digging if needed to avoid existing utilities. It is an average over a wide range of projects, assuming that some projects near roads or existing utilities will cost more, and that long straight stretches will be cheaper.

We note that this cost is not applicable in very dense urban areas where most fiber must be under a sidewalk or road (that type of construction is covered in the dense urban category below), so these are in a separate category. Similarly, extremely rocky areas are covered in the mountain category, and low-density areas with few existing underground utilities and little or no required restoration are covered in the desert/plains category.

Table 7: New Underground Construction Cost

LABOR				
DESCRIPTION	**QUANTITY**	**UNIT**	**COST/ UNIT**	**TOTAL COST**
Design	1	Mile	$300.00	$300
Conduit Plow/Trench	0	Foot	$6.00	$0
Conduit Boring	5,280	Foot	$10.00	$52,800
Place Inner Duct	5,280	Foot	$0.75	$3,960
Place Vault	10	Each	$150.00	$1,500
Rod and Rope Conduit	5,280	Foot	$1.50	$7,920
Place Fiber	5,280	Foot	$0.75	$3,960
Place Splice Case	1	Each	$300.00	$150
Splicing	6	Each	$30.00	$180
QC	429	lot	$1.00	$215
TOTAL LABOR				**$70,985**
MATERIAL				
2" Rolled Duct	5,280	Foot	$1.00	$5,280
12 Count Fiber	6,072	Foot	$0.40	$2,429
1" Inner Duct	5,280	Foot	$0.50	$2,640
Vaults	10	Each	$100.00	$1,000
Copper Tracer/Ground Wire	5,280	Foot	$0.34	$1,795
Splice Case	1	Each	$275.00	$138
Tax and Freight				$1,328
TOTAL MATERIAL				**$14,610**
TOTAL MATERIAL and LABOR				**$85,594**

3.5 Metro Underground—Dense Urban—New

Reflecting the higher cost of new construction in dense urban areas, this category has a higher estimated per-mile cost than the metro underground category—$220,000 per mile, on average. This category covers the highest cost portions of metropolitan area construction, where most construction must be done under streets and sidewalks, requiring more expensive restoration and coordination with existing utilities.

This category of construction is only one type of construction in the Dense Metro typology, comprising a small percentage of the total. The majority of the construction is aerial or conventional Underground—New construction.

Table 8: New Metro Underground—Dense Urban Construction Cost

LABOR				
DESCRIPTION	**QUANTITY**	**UNIT**	**COST/ UNIT**	**TOTAL COST**
Design	1	Mile	$300.00	$300
Conduit Plow/Trench	0	Foot	$6.00	$0
Conduit Boring	5,280	Foot	$10.00	$52,800
Restoration and Repair	5,280	Foot	$25.00	$132,000
Place Inner Duct	5,280	Foot	$0.75	$3,960
Place Vault	10	Each	$150.00	$1,500
Rod and Rope Conduit	5,280	Foot	$1.50	$7,920
Place Fiber	5,280	Foot	$0.75	$3,960
Place Splice Case	1	Each	$300.00	$150
Splicing	6	Each	$30.00	$180
QC	429	lot	$1.00	$215
TOTAL LABOR				**$202,985**
MATERIAL				
2" Rolled Duct	5,280	Foot	$1.00	$5,280
12 Count Fiber	6,072	Foot	$0.40	$2,429
1" Inner Duct	5,280	Foot	$0.50	$2,640
Vaults	10	Each	$100.00	$1,000
Copper Tracer/Ground Wire	5,280	Foot	$0.34	$1,795
Splice Case	1	Each	$275.00	$138
Tax and Freight				$1,328
TOTAL MATERIAL				**$14,610**
TOTAL MATERIAL and LABOR				**$217,594**

3.6 Metro Underground—Existing Conduit

Pulling cable through existing conduit is possible where a fiber provider has available underground facilities or can obtain them from the local government or other provider. As with overlash, this type of construction must be done by an incumbent entity or in partnership with one. The cost estimate for this category (about $28,000 per mile) is purely the capital cost and does not include any conduit lease costs.

Table 9: Metro Underground—Existing Conduit Construction Cost

LABOR				
DESCRIPTION	QUANTITY	UNIT	COST/ UNIT	TOTAL COST
Design	1	Mile	$300.00	$300
Conduit Plow/Trench	0	Foot	$6.00	$0
Conduit Boring	0	Foot	$10.00	$0
Place Inner Duct	0	Foot	$0.75	$0
Place Vault	0	Each	$150.00	$0
Rod and Rope Conduit	5,280	Foot	$3.00	$15,840
Place Fiber	5,280	Foot	$1.50	$7,920
Place Splice Case	1	Each	$300.00	$150
Splicing	6	Each	$30.00	$180
QC	825	lot	$1.00	$413
TOTAL LABOR				**$24,803**
MATERIAL				
2" Rolled Duct	0	Foot	$1.00	$0
12 Count Fiber	6,072	Foot	$0.40	$2,429
1" Inner Duct	0	Foot	$0.50	$0
Vaults	0	Each	$100.00	$0
Splice Case	1	Each	$275.00	$138
Tax and Freight				$257
TOTAL MATERIAL				**$2,823**
TOTAL MATERIAL and LABOR				**$27,625**

3.7 Rural Underground—Existing Conduit

As with metro underground construction in existing conduit, rural underground construction in existing conduit is possible where the provider has available conduit capacity or can obtain conduit from the local government or another provider. In a rural environment, the conduit would typically be owned by the telephone company and would either be spare conduit or conduit with low-count fiber or copper that would need to be replaced with high-count fiber. The per-mile cost here—about $16,000—does not include conduit lease fees, and incorporates labor rates that are lower than in metro areas.

Table 10: Rural Underground—Existing Conduit Construction Cost

LABOR				
DESCRIPTION	QUANTITY	UNIT	COST/ UNIT	TOTAL COST
Design	1	Mile	$300.00	$300
Conduit Plow/Trench	0	Foot	$4.50	$0
Conduit Boring	0	Foot	$10.00	$0
Place Inner Duct	0	Foot	$0.75	$0
Place Vault	0	Each	$150.00	$0
Rod and Rope Conduit	5,280	Foot	$1.50	$7,920
Place Fiber	5,280	Foot	$0.75	$3,960
Place Splice Case	1	Each	$300.00	$150
Splicing	6	Each	$30.00	$180
QC	429	lot	$1.00	$215
TOTAL LABOR				**$12,725**
MATERIAL				
2" Rolled Duct	0	Foot	$1.00	$0
12 Count Fiber	6,072	Foot	$0.40	$2,429
1" Inner Duct	0	Foot	$0.50	$0
Vaults	0	Each	$100.00	$0
Splice Case	1	Each	$275.00	$138
Tax and Freight				$257
TOTAL MATERIAL				**$2,823**
TOTAL MATERIAL and LABOR				**$15,547**

3.8 Mountain Underground—New

The $429,000-per-mile estimate for new underground construction is for the most challenging part of mountain terrain, where conventional directional boring cannot be done. Different drilling bits and equipment must be used (or example, an air hammer is used to break up solid rock and a rail head is attached to a directional drilling machine to break through scattered rock). In addition to the expense of this specialized equipment, these methods are much more time consuming than standard boring—which means that labor costs are much higher. The majority of mountain construction is aerial, and the majority of underground construction is typical Underground—New construction.

Table 11: New Mountain Underground Construction Cost

LABOR				
DESCRIPTION	**QUANTITY**	**UNIT**	**COST/ UNIT**	**TOTAL COST**
Design	1	Mile	$300.00	$300
Conduit Plow/Trench	0	Foot	$6.00	$0
Conduit Boring	5,280	Foot	$10.00	$52,800
Rock Adder (Hard Rock)	5,280	Foot	$65.00	$343,200
Place Inner Duct	5,280	Foot	$0.75	$3,960
Place Vault	10	Each	$150.00	$1,500
Rod and Rope Conduit	5,280	Foot	$1.50	$7,920
Place Fiber	5,280	Foot	$0.75	$3,960
Place Splice Case	1	Each	$300.00	$150
Splicing	6	Each	$30.00	$180
QC	429	lot	$1.00	$215
TOTAL LABOR				**$414,185**
MATERIAL				
2" Rolled Duct	5,280	Foot	$1.00	$5,280
12 Count Fiber	6,072	Foot	$0.40	$2,429
1" Inner Duct	5,280	Foot	$0.50	$2,640
Vaults	10	Each	$100.00	$1,000
Copper Tracer/Ground Wire	5,280	Foot	$0.34	$1,795
Splice Case	1	Each	$275.00	$138
Tax and Freight				$1,328
TOTAL MATERIAL				**$14,610**
TOTAL MATERIAL and LABOR				**$428,794**

3.9 Desert/Plains Underground—New

Our estimated cost for new underground fiber construction in desert and plains areas is about $65,000 per mile, based on unit contractor costs for large scale projects in rural environments. This cost estimate reflects the use of plowing. Plowing is cheaper than Underground—New. It can be done in these areas because existing utilities can be easily avoided and restoration is simple.

Table 12: New Desert/Plains Underground Construction Cost

LABOR				
DESCRIPTION	**QUANTITY**	**UNIT**	**COST/ UNIT**	**TOTAL COST**
Design	1	Mile	$300.00	$300
Conduit Plow/Trench	5,280	Foot	$6.00	$31,680
Conduit Boring	0	Foot	$10.00	$0
Place Inner Duct	5,280	Foot	$0.75	$3,960
Place Vault	10	Each	$150.00	$1,500
Rod and Rope Conduit	5,280	Foot	$1.50	$7,920
Place Fiber	5,280	Foot	$0.75	$3,960
Place Splice Case	1	Each	$300.00	$150
Splicing	6	Each	$30.00	$180
QC	429	lot	$1.00	$215
TOTAL LABOR				**$49,865**
MATERIAL				
2" Rolled Duct	5,280	Foot	$1.00	$5,280
12 Count Fiber	6,072	Foot	$0.40	$2,429
1" Inner Duct	5,280	Foot	$0.50	$2,640
Vaults	10	Each	$100.00	$1,000
Copper Tracer/Ground Wire	5,280	Foot	$0.34	$1,795
Splice Case	1	Each	$275.00	$138
Tax and Freight				$1,328
TOTAL MATERIAL				**$14,610**
TOTAL MATERIAL and LABOR				**$64,474**

4. Last-Mile Fiber Mileage

Based on our engineering methodology and standardized typologies, we made a series of assumptions regarding average last-mile fiber distances in rural, desert, mountain, plains, and metro areas. Table 13 lists the estimated per-Anchor fiber construction distances for each of these typologies.

Table 13: Range of Last-Mile Fiber Construction Required per Unserved Anchor (Miles)

	Dense Metro	Intermediate Metro	Low-Density Metro	Desert	Plains	Rural Western	Rural Eastern Mountain	Rural Eastern
Low	0.4	0.8	1.5	2.3	1.4	1.1	0.9	1.4
High	0.6	1.3	2.5	3.9	2.3	1.7	1.6	2.3

4.1 Rural, Desert, Mountain, and Plains Areas

For rural (non-Metro) areas, we developed estimates of average last-mile fiber distances by progressively narrowing our focus from the entire typology down to a typical individual Anchor in five sample study areas selected as representative of the regions, based on review of GIS data:

1. Desert—Southeastern Utah and Northwestern Arizona
2. Plains—Oklahoma Panhandle
3. Rural Western—Central Arizona, Western and Northwestern Idaho
4. Rural Eastern Mountain—Central West Virginia
5. Rural Eastern—Northern Alabama and Eastern Kentucky

In each of these study areas, we used a GIS-based approach to plot the Anchors, telephone company central offices (as likely interconnection points), and roads. We created fiber routes to connect the Anchors to central offices over the roads. Where feasible, we connected multiple Anchors over the same routes.

We then measured the fiber route lengths; divided the total mileage in each study area by the number of Anchors; and rounded the mileage to the next highest mile to account for a range of contingencies, such as potential barriers or impediments in the route and unavailability of easements.

4.2 Metro Areas

In Metro Areas, the model assumes connection distances ranging from 0.5 miles to 2 miles for Anchors. This assumption is based on the availability of FTTP service, cable TV service, or telephone service from an incumbent or competitive local exchange carrier. The assumptions are described in more detail in Section 2.1.

5. Building Entry and Electronics Costs

We estimated the average cost for constructing a fiber drop from the public right-of-way into an Anchor building, including terminating the fiber on a panel in the facility, at $2,000 to $4,000 (depending on typology). Drop and installation costs will vary widely in practice based on such factors as the varying percentages of aerial and underground drops, and the relative cost and complexity of underground construction in some areas. For example, building entry could be as simple as running an aerial drop from a pole to the side of the building and entering where the current telephone service comes into the building; it could also be as complex as boring from the right-of-way under a road and parking lot to reach the building.

Aerial drop installation (all construction from the right-of-way to the indoor panel, including building entry and termination) is priced at approximately $2,000. Underground drop installation is approximately $5,000. Prevailing aerial and underground percentages in the right-of-way are used to estimate the drop aerial and underground percentages.

The cost of electronics for delivery of Ethernet services to an Anchor will also vary. There will be a diverse range of existing infrastructure already in the Anchors, and other enhancements might be needed. Our model focuses on consistent delivery of 1 Gbps Ethernet service. We assumed an average cost for premises and core electronics, based on our experience specifying similar equipment for network projects nationwide. In metro areas, we estimate $10,000 for an Ethernet switch and the corresponding optics that need to be put in place at the central office or another location where the service is terminated within the service provider's network. In rural areas where distances are longer, we estimate $15,000 to cover the higher-cost long-haul optics.

6. Enhancing Connectivity to Interconnection Points

Our model includes the cost of fiber mileage from a backbone or middle-mile fiber interconnection point or a central office to an Anchor. However, we note that an initiative to address only fiber from a central office to an Anchor will leave many Anchors with significant bandwidth challenges—because effective broadband to Anchors depends on a robust connection to internet access. Thus, we also estimated the fiber construction that may be necessary to connect a central office that currently does not have fiber to an adjacent central office or other location for internet access.

In many rural areas, individual Anchors are connected to a district office or central office and have only limited connectivity to the internet backbone or to a state network. For example, an Anchor may have a 1 Gbps connection to a central office, but may share a 100 Mbps connection from the central office back to the internet with several other Anchors, plus all of the residents and businesses in a multi-county area.

In scenarios such as this, the Anchor faces high costs, limited bandwidth, and low reliability despite the fact that the Anchor does, in fact, have fiber connectivity.

It is possible to estimate the scale of an initiative enhancing central office connectivity in rural areas, and to further refine it with additional input from telephone companies, as well as input from Anchors. We note there are 6,500 central offices in the areas we have categorized as rural. The distance between central offices in rural areas ranges from 10 to 25 cable miles, depending on density. Assuming that 10 percent of central offices (650) require connectivity, 15 miles of construction are needed per central office, and the cost of construction is $50,000 per mile, we developed an order-of-magnitude estimate of $500 million to enhance connectivity to central offices.

Appendix A: Metadata

The following metadata sources describe the filters underpinning our standardized typologies. We conducted our analysis using Esri ArcGIS software, importing data from the U.S. Census Bureau, the U.S. Environmental Protection Agency (EPA), and the U.S. Geographic Names Information System (GNIS).

Table 14: Metadata Sources

Typology	Metadata Source
United States	Esri U.S. States shapefile (see attached)
Metro Areas	U.S. Census Urbanized Areas (see attached)
Desert	EPA level I ecoregion classifications, excluding Metro Areas[10]
Plains	EPA level I ecoregion classifications, excluding Metro Areas and Desert[11]
Rural Western	Esri U.S. States shapefile, west of Plains, excluding previous categories
Rural Eastern Mountain	Esri U.S. Geographic Names Information System Summits shapefile (see attached)
Rural Eastern	Esri U.S. States shapefile, east of Plains, excluding previous categories

[10] "Ecoregions of North America: Level I Ecoregions," U.S. Environmental Protection Agency, https://www.epa.gov/eco-research/ecoregions-north-america (accessed December 26, 2017).
[11] Ibid.