October 17, 2014

Chairman Tom Wheeler
Commissioner Mignon Clyburn
Commissioner Jessica Rosenworcel
Commissioner Ajit Pai
Commissioner Mike O'Rielly
445 12th St. SW
Washington, DC 20554

RE: Ex parte presentation in WC Docket No. 13-184

Dear Mr. Chairman and Commissioners:

The SHLB Coalition hereby submits into the E-rate Modernization proceeding the attached study estimating the one-time costs of deploying fiber optics to the schools and libraries without such broadband infrastructure. The study, called "A Model for Understanding the Cost to Connect Schools and Libraries with Fiber Optics," was prepared for the SHLB Coalition by CTC Technology & Energy, one of the nation's premier engineering and business consulting firms. CTC has engaged in engineering studies for hundreds of fiber networks across the country and has enormous expertise in costing and designing fiber networks. CTC developed six cost models that reflect the actual costs encountered in different geographic regions of the U.S.[1]

This cost study documents the investment in broadband that is needed to ensure that our nation's schools and libraries have scalable, high-capacity broadband for the future. The SHLB Coalition believes that the E-rate program must explicitly encourage greater capital investment to accomplish the broadband connectivity goals set forth by the FCC in its July 2014 E-rate Modernization Order and by the President in his ConnectED Initiative. Investing in long-lasting, "future-proof" facilities will yield significant cost savings in the future, because the recurring costs of operating state-of-the-art fiber networks are often less than the costs of maintaining outdated network technologies. Capital expenditures to support scalable, high-capacity fiber networks are thus likely to yield more affordable recurring rates for schools and libraries. Most important, investing in this infrastructure will lay the foundation for students, teachers, and learners of all ages to develop the technological skills needed to participate in the 21st century economy.

[1] Because of the unique geographic characteristics of Alaska, the study was not able to address the costs of deploying fiber in that state. We recommend additional study of the broadband deployment costs for schools and libraries in Alaska.

This study also highlights the need to focus special attention on the broadband needs of schools and libraries in rural areas. Rural schools and libraries cannot and should not be left behind in the transition to broadband; rather, the Commission should adopt additional measures to make the resources available to ensure that rural schools and libraries literally get "up to speed" with their urban counterparts. This study documents what it will take to close the "Rural Fiber Gap" identified by Chairman Wheeler in his speech to the 2d Ed Tech Summit last month.[2] The data also provides support for closing the "capacity gap" identified by several library and school organizations in their joint letter filed on Oct. 14.[3] The survey released earlier this week by the Consortium for School Networking (CoSN) and AASA – the School Superintendents Association shows that over 80% of school districts believe the E-rate program's current funding levels are not meeting their needs, and found that "[c]apital, upfront non-recurring costs [are] the second biggest barrier to increasing robust Internet connectivity in school districts."[4]

The SHLB Coalition has previously submitted several comments in this proceeding in support of enhancing the E-rate program's support for capital investment in broadband networks, especially in rural areas. We take this opportunity to summarize below our recommendations for changes to the E-rate program that will provide greater incentives for capital investment and cost savings:

1. Additional funding is necessary for the E-rate program to accomplish the objectives of connecting all schools and libraries with high-capacity broadband.

2. Schools and libraries should have the option to self-construct their own fiber networks when it is cost-effective, as is permitted in the Healthcare Connect Fund.

3. The treatment of dark fiber and lit fiber should be equalized, so that dark fiber is not discriminated against and so that schools and libraries can choose this option if it is more cost-effective than other options.

4. Schools and libraries should have the option to amortize capital deployment costs over several years (not limited to 3 years or 5 years) in order to reduce the monthly expenses.

5. Establishing a maximum contract length of just 5 years will be detrimental to state master contracts. State master contracts are often over 5 years in length, and limiting the simplified process for E-rate applications to contracts of five years or less will make it difficult to take advantage of the lower rates available in state master contracts.

6. A certain portion of any increase in E-rate funding should be allocated specifically for capital expenditures (build-out) in rural areas. The CapEx program would be open to all providers and would be available over the next 5-8 years (to give schools/libraries the time to apply).

7. The FCC should explicitly allow E-rate supported services/networks to be shared with health care and other community uses. E-rate funded networks should also be open to

---

[2] http://www.fcc.gov/document/fcc-chairman-tom-wheeler-remarks-second-ed-tech-summit.
[3] http://apps.fcc.gov/ecfs/document/view?id=60000973304.
[4] http://cosn.org/about/news/k-12-report-affordability-adequate-funding-biggest-technology-barriers.

interconnection by other networks (as long as the E-rate program does not pay for these additional uses.) By allowing interconnection, schools and libraries can often become intermediate “jumping off” points from which it can be possible to serve the surrounding community. By permitting network sharing, the E-rate program can facilitate cost-savings by taking advantage of existing investments made by incumbent telcos, cable providers, municipalities, research and education networks, and other competitive providers.

8. The FCC should allow “remote rural” schools/libraries an additional five percent increase in E-rate support, thereby increasing the maximum to 95% (and lowering the match to 5%). Further, in order to encourage the use of consortia, the FCC should allow all consortia approved by state government school and/or library agencies to receive an additional five percent discount, regardless of the size of the consortia.

9. The FCC should adjust the newly-adopted definition of “urban” so that schools and libraries in urban clusters are considered "rural" and receive the additional rural discount.

10. The FCC should allow broadband providers expedited recovery of capital expenses in one or two years in exchange for a commitment to offer more affordable rates thereafter (in other words, award capex funds only on condition that the provider guarantees affordable rates).

11. The FCC should enable USAC to approve multi-year awards (as in the rural Healthcare Connect Fund).

Sincerely,

John Windhausen, Jr.
Executive Director
SHLB Coalition
jwindhausen@shlb.org
(202) 256-9616

ctc technology & energy

engineering & business consulting

A Model for Understanding the Cost to Connect Schools and Libraries with Fiber Optics

Prepared for the Schools, Health & Libraries Broadband Coalition

October 2014

Columbia Telecommunications Corporation

10613 Concord Street • Kensington, MD 20895 • Tel: 301-933-1488 • Fax: 301-933-3340 • www.ctcnet.us

Table of Contents

Figures

Tables

1. Executive Summary

This report provides a model for understanding the cost to build world-class broadband communications to the schools and libraries that are not currently connected with adequate infrastructure. The report analyzes the various elements of the cost of extending fiber optics—the technology best suited to provide reliable 1 Gbps and beyond service—to schools and libraries that do not currently have direct optical fiber connections.[1]

In brief summary, the model, which is described in detail below, begins by estimating the number of U.S. schools and libraries that currently require connections. It then divides the country into six standardized geographies from an engineering and network construction standpoint and estimates the average cost to connect a single school or library within each geography. The cost estimate includes extension of fiber from an interconnection point[2] to the schools and libraries, building entry, installation of premises electronics at the school or library, and incremental upgrade of optics at the interconnection point. It is not inclusive of any major upgrades of electronics. (Some telephone company central offices, for example, may have insufficient or outdated network electronics.)

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

The model also relies on the reasonable assumptions that there will be opportunities to leverage existing communications infrastructure to complete this project, such as using existing underground conduit and overlashing fiber to existing aerial strand and cables. It thus assumes

---

[1] A direct fiber connection is the optimal technical solution and most future-proof investment for connecting a school or library. Once built, that fiber connection is infinitely scalable to higher speeds as the electronics develop and come down in cost. Fiber itself, so long as it is maintained, is a long-term investment. While we know that other technologies, including wireless technologies, are improving in their speed capabilities, all of those technologies require fiber very deep into a neighborhood to realize high speeds. For example, delivering a reliable Gigabit service over a wireless network would require fiber almost to the premises of the facility to be served, or fiber to a point with an unobstructed line of sight, and would likely require licensed spectrum. Inexpensive wireless equipment is a relatively short-term solution and short-term investment, because it would need to be replaced every five or so years. We also note that many of the potential speeds that developers and manufacturers have achieved over wireless and other technologies in the lab are not replicable in the field.

[2] We use "interconnection point" as a generic term for a place where the fiber can connect to the network of a willing and able provider. While that interconnection point might be owned by a local exchange carrier, it might also be operated by a research and education (R&E) network, a publicly owned regional network, a cable operator, or some other provider in the area.

that telecommunications and cable operators will be key partners in this effort. Similarly, the model assume a certain scale of projects and that construction will be coordinated on a regional or state-wide basis; small per-facility or per-district projects will not achieve the same per-unit pricing as larger-scale projects and could more than double the estimated construction costs.

The model analyzes the one-time deployment costs for connecting schools and libraries in the continental United States and Hawaii.[3] The model does not include recurring service expenses.

1.1 Connecting Schools

The average cost to connect each school with last-mile fiber—including constructing the last-mile fiber, bringing the fiber into the building, and acquiring and activating the network electronics—ranges across geographies, from $40,000 for a school in a dense metropolitan area to $600,000 for an isolated school in a desert area (Table 1).

Table 1: Average Cost to Connect a School

Geography	Average Cost
Metro Areas	$40,000 - $104,000
Desert	$596,000
Plains	$324,000
Rural Western	$317,000
Rural Eastern Mountain	$205,000
Rural Eastern	$185,000

The model estimates the average cost of construction from the school or library to an interconnection point, such as a central office or equivalent fiber endpoint (e.g., fiber cabinet or

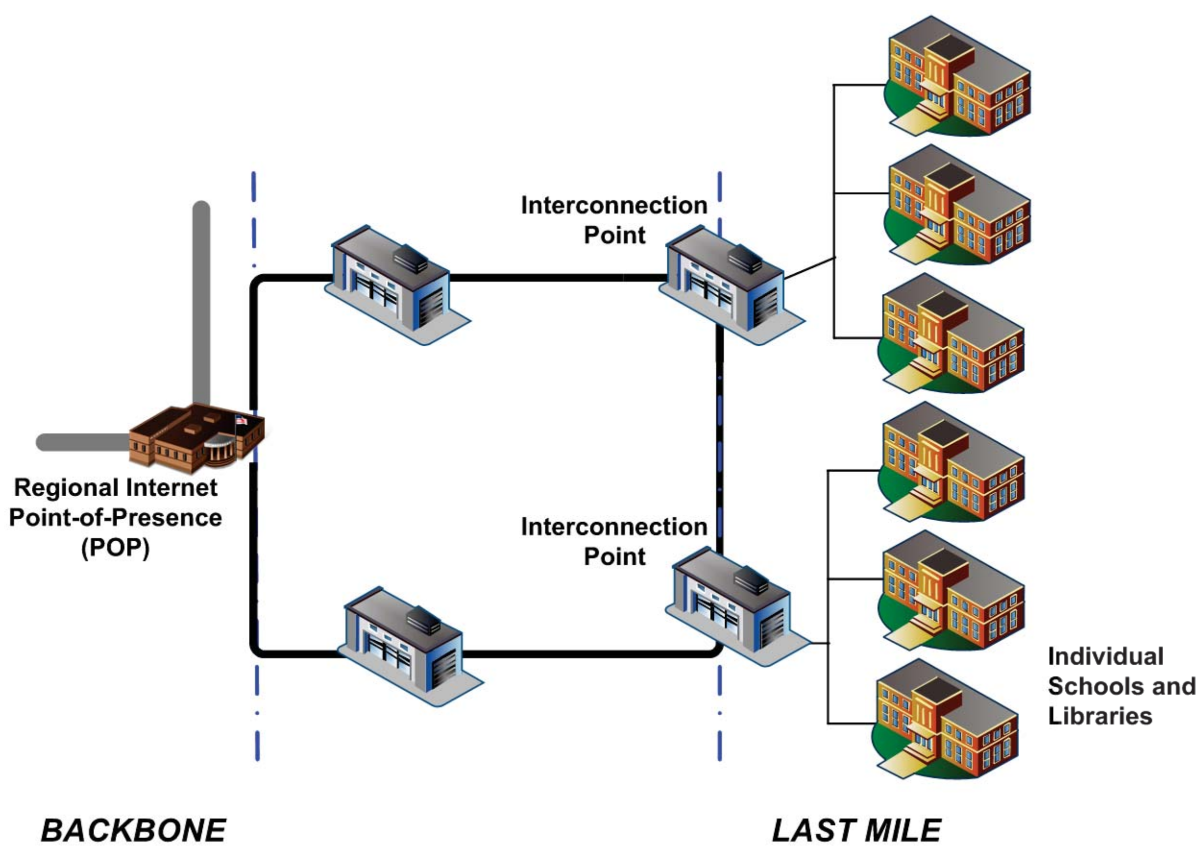
[3] Alaska is not included in the model because it cannot be categorized accurately in the analysis without state-specific information that is not publicly available. Because many separate Alaskan rural areas are not directly connected by road or fiber, central office connectivity is different case-by-case, and applying the 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, schools, and libraries can affordably construct fiber, and 3) areas where satellite communications is the best option. Hawaii is included in the model, divided between Metro Areas and Rural Western areas.

hybrid fiber-coaxial node). The model includes high and low estimates, bounding the main areas of uncertainty.

In metropolitan areas, schools can typically access fiber at an interconnection point that is 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, the model assumes that fiber exists within 0.5 to two miles of the school.

The model estimates the cost of constructing fiber from schools in rural areas to interconnection points like central offices, which typically have fiber optic connectivity back to a regional Internet point-of-presence (Figure 1). The estimated distances required to connect schools in various areas are discussed in Section 4.

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



Because almost all schools are connected by telephone lines and/or cable TV, it can be safely assumed that there is some sort of existing communications infrastructure between a central office and a school. Therefore it is technically possible to use existing infrastructure in many locations to assist in placing fiber to the schools. As discussed in Section 3, the model assumes that half the fiber required to connect schools is either overlashed to existing aerial strand or placed in existing underground conduit.

1.2 Connecting Libraries

The cost to connect libraries is lower than the cost to connect schools for a number of reasons. First, there are almost seven times as many schools as libraries that need to be connected. Second, the cost to connect an individual library is typically lower because, relative to schools, libraries are more likely to be close to population centers and interconnection points. Therefore connecting them will not require as many miles of fiber as connecting a similar number of schools. However, the FCC's best estimate is that a larger percentage of libraries need to be connected, relative to schools.[4]

The cost estimate for libraries also assumes coordination with projects to connect schools, so that construction is executed as a large-scale statewide or regional project. This approach takes advantage of economies of scale.

The average cost to connect a library ranges from $40,000 in metropolitan areas to $275,000 in rural desert areas (Table 2).

Table 2: Average Cost to Connect a Library

Geography	Average Cost
Metro Areas	$40,000 - $59,000
Desert	$275,000
Plains	$55,000
Rural Western	$94,000
Rural Eastern Mountain	$56,000
Rural Eastern	$60,000

[4] *E-Rate Modernization Data*, White Paper Direct Access to Broadband Connectivity Datasets – Updated 8 Oct 2014. Retrieved Oct. 12, 2014 from transition.fcc.gov/wcb/White_Paper_Direct_Access_Broadband100814.zip.

Although the fiber distance required to connect a library is low compared to schools in rural areas, the per-unit construction cost in rural areas is somewhat higher; the construction is more likely to take place in or near towns, as opposed to lower-cost construction in sparse, remote areas.

1.3 Summary of Methodology

Our methodology included four primary steps, each of which is described in detail later in this report:

1. Drawing on data from the FCC, the U.S. Department of Education's National Center for Education Statistics (NCES), and the Institute of Museum and Library Services, the model estimates the number of U.S. schools and libraries that currently require connections (Section 1.4).

2. 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), the model divides the country into six standardized geographies from an engineering and network construction standpoint. These geographies are illustrated in Figure 2 below and defined in more detail in Section 2:

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

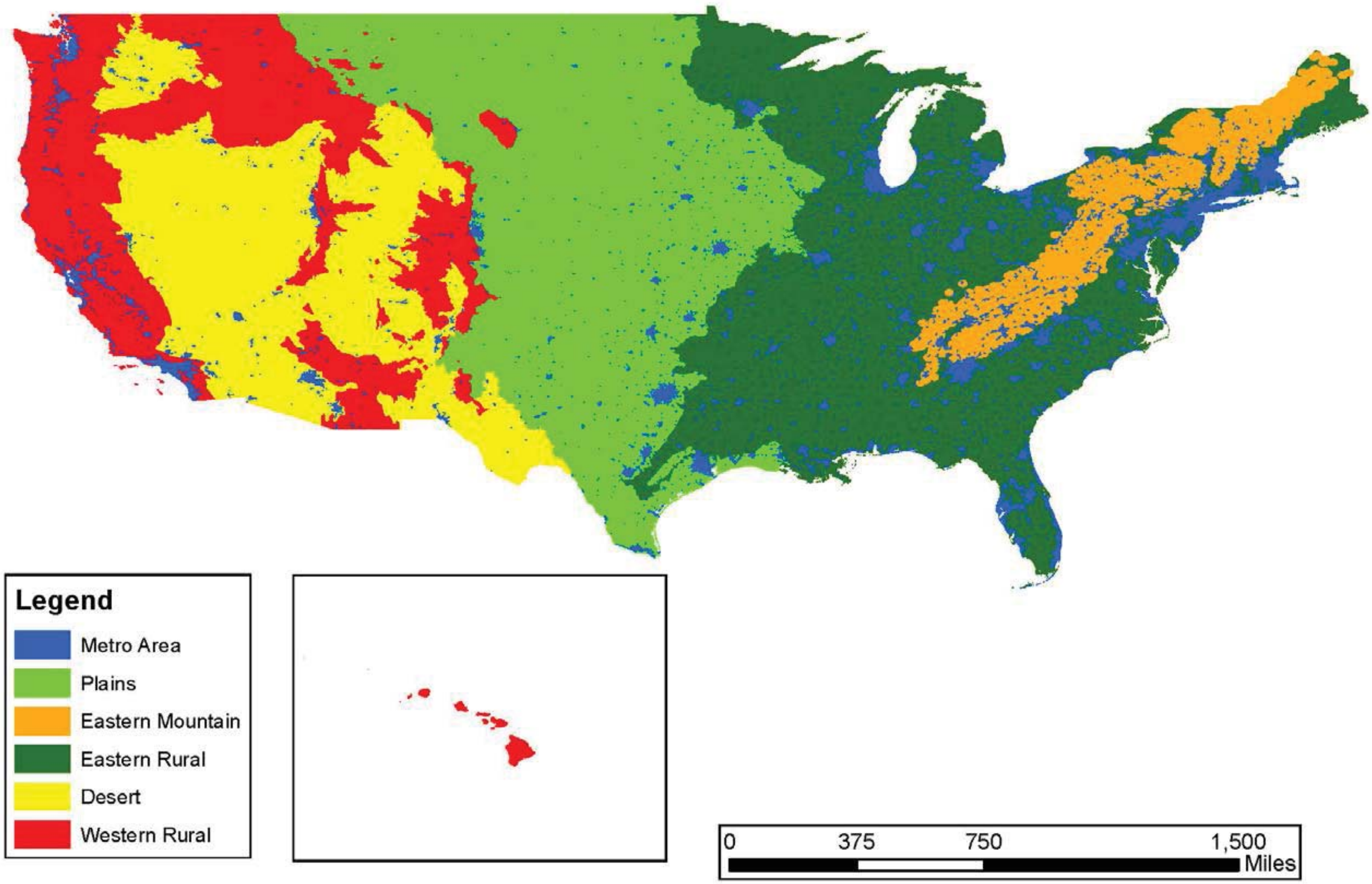
3. The model estimates the average cost to connect a single school or library within each geography, including costs for:

    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 schools without fiber are equally likely to be close to an interconnection point as a school with fiber. The high estimate assumes that schools without fiber are more likely to be distant from the interconnection point. The model also estimates the cost of fiber construction to connect central offices that do not have fiber to an adjacent central office or other location for Internet access. These costs are described in Sections 3 through 6.

4. Based on the likely number of schools and libraries that require fiber in each geography and the order-of-magnitude cost per mile to construct fiber in the different geographies, we calculated high-level estimates of the total cost of connecting the facilities (see Section 7 and Section 8).

Figure 2: Standardized Geographies



1.4 Estimate of How Many Schools and Libraries Require Connections

To understand how many schools and libraries still require direct fiber connections, we analyzed the most comprehensive and recent data compiled by the Federal Communications Commission (FCC),[5] which estimates the percentages of schools and libraries that report either that they have no fiber connection or that they do not know whether they have fiber (Table 3).

Table 3: Estimate of Schools and Libraries that Need Fiber

Type of Institution	No fiber connection	Fiber connectivity unknown
Rural schools	42 percent	22 percent
Non-rural schools	44 percent	17 percent
Libraries	33 percent	52 percent

Drawing on these data from the FCC, the U.S. Department of Education's National Center for Education Statistics (NCES),[6,7] and the Institute of Museum and Library Services,[8] we developed estimates of the number of U.S. schools and libraries that currently are directly connected over fiber and the number that require connections.

Our analysis of the FCC data finds that 42 percent of rural schools[9] report having no fiber and 44 percent of non-rural schools report having no fiber. In addition, 22 percent of rural schools and 17 percent of non-rural schools were listed as unknown. Either they did not report fiber connectivity, they reported that they did not know the status of their fiber connectivity, or they had multiple, inconsistent reports.

---

[5] *E-Rate Modernization Data*, White Paper Direct Access to Broadband Connectivity Datasets – Updated 8 Oct 2014. Retrieved Oct. 12, 2014 from transition.fcc.gov/wcb/White_Paper_Direct_Access_Broadband100814.zip.

[6] Keaton, P. (2014). *Documentation to the NCES Common Core of Data Public Elementary/Secondary School Universe Survey Preliminary Directory File: School Year 2012-13* (NCES 2014-053). U.S. Department of Education. Washington, DC: National Center for Education Statistics. Retrieved Oct. 7, 2014 from http://nces.ed.gov/pubsearch (http://nces.ed.gov/ccd/pdf/psu12pgen.pdf.

[7] Broughman, S.P., Tourkin, S., Swaim, N.L., Peterson. J, Parmer R., Zotti A., and Andriani S (2012). Private School Universe Survey (PSS): Public-Use Data File User's Manual for School Year 2009–10 (NCES 2012-322). U.S. Department of Education. Washington, DC: National Center for Education Statistics. Retrieved Oct. 7, 2014 from http://nces.ed.gov/pubsearch (http://nces.ed.gov/pubs2011/2011322.pdf.

[8] Swan, D. W., Grimes, J., Owens, T., Miller, K., Arroyo, J., Craig, T., Dorinski, S., Freeman M., Isaac, N., O'Shea, P., Padgett, R., & Schilling, P. (2014). *Data File Documentation: Public Libraries Survey: Fiscal Year 2012* (IMLS-2014–PLS-02). Institute of Museum and Library Services. Washington, DC. Retrieved Oct. 7, 2014 from http://www.imls.gov/research/ (http://www.imls.gov/assets/1/AssetManager/fy2012_pls_data_file_documentation.pdf).

[9] We identified rural schools as schools with New Urban-Centric Locale Codes 41 through 43. All other schools are non-rural. Retrieved Oct. 12, 2014 from http://nces.ed.gov/ccd/rural_locales.asp.

The model splits the unknown school category in half and assigns an equal amount to the fiber-connected and no-fiber categories. For both rural and non-rural categories, based on this assignment of the unknowns, 53 percent have no fiber and 47 percent have fiber. These percentages are used in the remainder of the analysis.

Our analysis of the FCC data finds that 33 percent of the libraries report having no fiber, and 52 percent of libraries were listed as unknown. Either they did not report fiber connectivity, they reported that they did not know the status of their fiber connectivity, or they had multiple, inconsistent reports.

The model splits the unknown library category in half and assigns an equal amount to the fiber-connected and no-fiber categories.[10] Based on this assignment of the unknowns, 59 percent have no fiber and 41 percent have fiber. These percentages are used in the remainder of the analysis.

[10] Assigning half of the "fiber unknown" libraries to the fiber-connected category may underestimate the percentage of libraries that need fiber, because rural libraries are more likely to report that they do not know their connection type. A recent report on digital literacy notes that, among libraries responding to a survey of their connectivity: "2689 of respondents noted that they did not know if their institution had fiber optic Internet. This ranged from a high of 21.3 percent for rural libraries and a low of 8.8 percent for city libraries, with 13.4 percent of suburban and 15.0 percent of town libraries reporting they were uncertain of their connection type… it is still clear that the likelihood of a library having access to fiber optic Internet increases significantly with the size of its population base." See: Bertot, J.C., Jaeger, P.T., Lee, J., Dubbels, K., McDermott, A.J., Real, B. (2014). 2013 Digital Inclusion Survey: Survey Findings and Results. College Park, MD: Information Policy & Access Center, University of Maryland College Park. Retrieved Oct. 14, 2014 from http://ipac.umd.edu/ (http://digitalinclusion.umd.edu/sites/default/files/uploads/2013DigitalInclusionNationalReport.pdf).

2. Standardized Geographies

The model addresses the diversity of existing physical plant and construction characteristics in the United States by dividing the country into six standardized geographies that—from an engineering and networking standpoint—reflect factors such as labor costs, population density, distances between schools, and the difficulty of building fiber in various terrains. Construction costs are more similar within these categories than they are within a particular state, because a state is often a mixture of these geographies.

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 geographies as:

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

The geographies are described below. Section 3 defines the construction categories that will be required in the different geographies, and Section 4 explains the average amount of fiber construction required in each.

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

The model's definition of metropolitan areas aligns with U.S. Census Bureau-defined urban areas.[11] 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 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

[11] "Cartographic Boundary Shapefiles - Urban Areas: 2013," U.S. Census Bureau. Retrieved Oct. 13 from https://www.census.gov/geo/maps-data/data/cbf/cbf_ua.html. *See also:* "2010 Census Urban and Rural Classification and Urban Area," U.S. Census Bureau. Retrieved Oct. 8, 2014 from https://www.census.gov/geo/reference/ua/urban-rural-2010.html.

the central business districts to the suburbs, the model averages that range within each category.

Aside from high population densities relative to rural geographies, 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 schools and libraries will not require extensive extended fiber construction.

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

The average fiber distance will increase with the average density of the metro areas. The model takes into account the fact that often the reason a school is not yet fiber connected is that it is not close to existing infrastructure and the built-up areas of the suburb. Another factor is that school districts often start with connecting fiber to high schools and middle schools and that an unconnected school is more likely to be an elementary school. Elementary schools are more likely to be more widely dispersed neighborhood schools and therefore further from interconnection points and existing fiber. Their presence in neighborhoods will also increase the percentage of underground fiber, relative to schools closer to larger, older rights-of-way.

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 schools and libraries 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, TN, and Reno, NV. Relative to a Dense Metro Area, there will be lower fiber density and therefore more instances where longer distances are needed to connect a school 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 the model have average population densities between 363 and 1,669 residents per square mile. Examples include Bristol, VA/TN, Sturgis, MI, and Springfield, VT. Relative to other metro areas, there will be lower fiber density and therefore more instances where longer distances are needed to connect a school to fiber. Furthermore, there will be a relatively higher percentage of low-density suburban areas with longer distances needed to connect schools. 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 and other interconnection points.

2.2 Desert

The Desert geography aligns with the EPA's level I ecoregion classifications.[12] We imported the EPA's dataset into Esri and applied it as a second filter, identifying all non-metro desert areas. The Desert geography 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, schools and libraries are the most widely dispersed of any of the geographies, and therefore total costs per school or library are high.

2.3 Plains

The Plains geography is defined in the 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 geography, but the area is less dense than the Rural Eastern geography.

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

[12] "Ecoregions of North America: Level I Ecoregions," U.S. Environmental Protection Agency. Retrieved Oct. 8, 2014 from http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Level%20I.

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 geography.

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 geographies. 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 schools and libraries.

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

2.6 Rural Eastern

In the model, the Rural Eastern geography 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 geography is defined by default as the areas remaining after applying all other filters.

This geography is more densely populated than the Rural Western areas. The model estimates 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-school basis, the model makes some basic assumptions based on network deployments in rural, urban, and suburban communities nationwide.

Based on a full range of objective and subjective factors, the model accounts for reasonable variations in per-unit construction cost, population density, and aerial and underground construction.

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

1. *The location of unserved schools/libraries*—we developed two different models (low and high), which make different assumptions about where unserved schools are located. The Low model assumes that unserved schools are distributed evenly among all schools; the High model assumes that unserved schools are the most distant schools from the interconnection points. The most outlying facilities, in terms of location relative to population density and interconnection points, are less likely to be fiber connected.

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

3. *The cost of construction (labor and materials)*—based on recent large-scale projects,[13] the model assumes 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 school or library connected.

4. *The scope of the construction projects*—the model assumes the construction of fiber to schools and libraries 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,

[13] These numbers were based on our experience designing networks in rural, urban, and suburban communities; our experience designing fiber connections to schools and libraries; and reasonable assumptions about the cost of extended last-mile fiber construction in different kinds of geographies.

significant procurement overhead, 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 network engineering and construction in a range of geographies. The model assumes that:

    a. The percentage of aerial and underground construction will vary by geography.

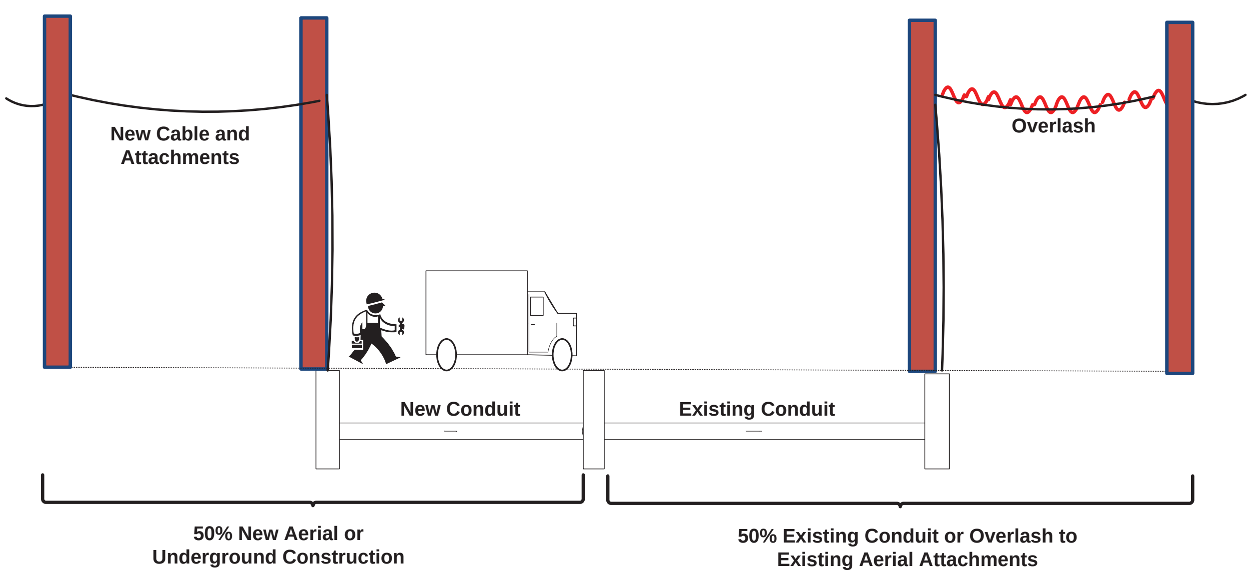
    b. New fiber will be overlashed to existing strand for half of all aerial construction.

    c. Existing conduit will be used for half of all underground construction.

    d. New construction will be required for the remaining half of both aerial and underground construction.

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 geographic area is composed of different mixtures of these construction categories, as listed in Table 4* 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 4: Distribution of Construction Categories Across Geographies

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

This category—constructing new fiber on aerial strand—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. The model reflects an estimate over a large ensemble of aerial construction projects in metropolitan and rural areas; because of the significant variations within all of the geographic categories, this number is an average.

Table 5: 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 and also 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 the 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, the model estimates 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 6: 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 7: 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, the model estimates 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 8: 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 geography, comprising a small percentage of the total. The majority of the construction is aerial or conventional Underground—New construction.

Table 9: 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 10: 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 11: 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 12: 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 13: 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 the engineering methodology and standardized geographies, the model includes a series of assumptions regarding average last-mile fiber distances in rural, desert, mountain, plains, and metro areas. The estimated fiber construction distances for each of these geographies are described in Table 14.

Table 14: Average Required Fiber Construction (Miles)

	Dense Metro	Intermediate Metro	Low-Density Metro	Desert	Plains	Rural Western	Rural Eastern Mountain	Rural Eastern
Schools	0.5	1.0	2.0	6 – 17	4 – 9	4 – 8	3 – 5	2 – 4
Libraries	0.5	1.0	2.0	7	1	2	1	1

4.1 Rural, Desert, Mountain, and Plains Areas

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

1. Desert—Central Nevada
2. Plains—Northwestern Nebraska
3. Rural Western—Northern California
4. Rural Eastern Mountain—Central West Virginia
5. Rural Eastern—Northern Mississippi

In each of these study areas, we used a GIS-based approach to plot the schools, libraries, telephone company central offices, and roads. We created fiber routes to connect the schools and libraries to central offices over the roads. Where feasible, we connected multiple schools and libraries over the same routes.

We then measured the fiber route lengths; divided the total mileage in each study area by the number of schools and libraries; 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 distance ranging from 0.5 miles to two miles for schools and 0.5 to one mile for libraries. 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 a school or library building, including terminating the fiber on a panel in the facility, at $2,000 to $4,000 (depending on geography). 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 a school will also vary. There will be a diverse range of existing infrastructure already in the schools, and other enhancements might be needed. The model, which focuses on consistent delivery of 1 Gbps Ethernet service, assumes an average cost for premises and core electronics, based on similar equipment specified for network projects nationwide. In metro areas, the model estimates $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, the model estimates $15,000 to cover the higher-cost long-haul optics.

6. Enhancing Connectivity to District Offices or Central Offices

The model includes the cost of fiber mileage from an interconnection point to a school or library. However, an initiative to address only fiber from a central office to a school or library will leave many schools and libraries with significant bandwidth challenges—because effective broadband to schools and libraries depends on a robust connection to Internet access. Thus, the model also estimates 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 schools are connected to a district office or central office and have only limited connectivity to the Internet backbone or to the state department of education or libraries. For example, a school 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 schools, plus all of the residents and businesses in a multi-county area.

In scenarios such as this, the school faces high costs, limited bandwidth, and low reliability despite the fact that the school 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 schools and libraries. There are 6,500 central offices in the areas 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.

7. Cost to Connect Schools

The total costs per school are itemized in Table 15 and Table 16 below. Table 15 indicates the analysis based on the high estimate—assuming that the schools without fiber tend to be more distant from the interconnection points. The weighted average connection cost per school is approximately $110,000. As the table illustrates, costs vary among the geographies. For example:

- The Desert geography represents approximately 1 percent of schools that need fiber connections, but 8 percent of the total project cost. Each school will cost, on average, $600,000 to connect with fiber.

- In the Plains geography, each school will cost on average $320,000 to connect. Similar to the desert geography, there are relatively few schools (approximately 5 percent of the total) but the high construction cost means that connecting all of them will add up to 16 percent of the total project cost.

- The connection cost of the Metro area schools ranges from $40,000 to $104,000, on average. This category comprises 75 percent of the schools to be connected but approximately 40 percent of the project cost.

Table 16 summarizes the low estimate model, where schools without fiber are assumed to have the same distance and distribution relative to the interconnection points as do schools with fiber. This results in a total estimate that is about 30 percent lower than the high model, with an average connection cost per school of approximately $75,000. In the low model, there is also a lower cost premium for connecting rural schools compared to metropolitan area schools.

- The Desert geography represents approximately 1 percent of schools that need fiber connections, but 4 percent of the total project cost. Each school will cost, on average, $220,000 to connect with fiber.

- In the Plains geography, each school will cost on average $150,000 to connect. Similar to the Desert geography, there are relatively few schools (approximately 5 percent of the total) but the high construction cost means that connecting all of them will add up to 11 percent of the total project cost.

- As with the high analysis, the connection cost of the Metro area schools ranges from $40,000 to $104,000, on average. In this analysis, however, the category is still 75 percent of the schools but increases from 40 percent to 57 percent of the project cost.

Table 15: Cost to Connect Schools—High Model

Description	Dense Metro	Intermediate Metro	Low Density Metro	Rural Eastern Mountain	Rural Western	Desert	Plains	Rural Eastern
Public Schools	35,136	23,535	14,494	2,833	2,789	1,612	6,533	14,149
Private Schools	12,808	7,116	3,582	761	375	144	427	3,034
Sum of Public and Private Schools	47,944	30,651	18,076	3,594	3,164	1,756	6,960	17,183
Schools without high speed data	19,178	12,260	7,230	1,078	949	527	2,088	5,155
Last mile fiber miles per school not served	0.5	1.0	2.0	5.0	8.0	17.0	9.0	4.0
Last mile aerial miles per school not served	0.3	0.5	1.0	4.5	7.2	12.8	6.8	2.0
Aerial cost per mile	$33,000	$33,000	$33,000	$32,000	$32,000	$32,000	$32,000	$32,000
Last mile aerial cost per school not served	$8,000	$17,000	$33,000	$144,000	$230,000	$408,000	$216,000	$64,000
Underground cost per mile	$73,000	$57,000	$57,000	$88,000	$88,000	$40,000	$40,000	$51,000
Last mile underground miles per school not served	0.3	0.5	1.0	0.5	0.8	4.3	2.3	2.0
Last mile underground cost per school not served	$18,000	$29,000	$57,000	$44,000	$70,000	$170,000	$90,000	$102,000
Aerial percentage of miles	50%	50%	50%	90%	90%	75%	75%	50%
Underground percentage of miles	50%	50%	50%	10%	10%	25%	25%	50%
Last mile fiber cost per school	$26,000	$46,000	$90,000	$188,000	$300,000	$578,000	$306,000	$166,000
Drop and installation cost per school	$4,000	$4,000	$4,000	$2,000	$2,000	$3,000	$3,000	$4,000
Network electronics per school	$10,000	$10,000	$10,000	$15,000	$15,000	$15,000	$15,000	$15,000
TOTAL COST PER SCHOOL	**$40,000**	**$60,000**	**$104,000**	**$205,000**	**$317,000**	**$596,000**	**$324,000**	**$185,000**

Table 16: Cost to Connect Schools—Low Model

Description	Dense Metro	Intermediate Metro	Low Density Metro	Rural Eastern Mountain	Rural Western	Desert	Plains	Rural Eastern
Public Schools	35,136	23,535	14,494	2,833	2,789	1,612	6,533	14,149
Private Schools	12,808	7,116	3,582	761	375	144	427	3,034
Sum of Public and Private Schools	47,944	30,651	18,076	3,594	3,164	1,756	6,960	17,183
Schools without high speed data	19,178	12,260	7,230	1,078	949	527	2,088	5,155
Last mile fiber miles per school not served	0.5	1.0	2.0	3.0	4.0	6.0	4.0	2.0
Last mile aerial miles per school not served	0.3	0.5	1.0	2.7	3.6	4.5	3.0	1.0
Aerial cost per mile	$33,000	$33,000	$33,000	$32,000	$32,000	$32,000	$32,000	$32,000
Last mile aerial cost per school not served	$8,000	$17,000	$33,000	$86,000	$115,000	$144,000	$96,000	$32,000
Underground cost per mile	$73,000	$57,000	$57,000	$88,000	$88,000	$40,000	$40,000	$51,000
Last mile underground miles per school not served	0.3	0.5	1.0	0.3	0.4	1.5	1.0	1.0
Last mile underground cost per school not served	$18,000	$29,000	$57,000	$26,000	$35,000	$60,000	$40,000	$51,000
Aerial percentage of miles	50%	50%	50%	90%	90%	75%	75%	50%
Underground percentage of miles	50%	50%	50%	10%	10%	25%	25%	50%
Last mile fiber cost per school	$26,000	$46,000	$90,000	$112,000	$150,000	$204,000	$136,000	$83,000
Drop and installation cost per school	$4,000	$4,000	$4,000	$2,000	$2,000	$3,000	$3,000	$4,000
Network electronics per school	$10,000	$10,000	$10,000	$15,000	$15,000	$15,000	$15,000	$15,000
TOTAL COST PER SCHOOL	**$40,000**	**$60,000**	**$104,000**	**$129,000**	**$167,000**	**$222,000**	**$154,000**	**$102,000**

8. Incremental Cost to Connect Libraries

Table 17 provides a summary of the library cost model. These costs assume coordinated projects with school construction. In the model, libraries and schools have the same per-mile construction costs and the same costs for drops and electronics in a given geography; therefore, the cost per library is similar in order of magnitude, no matter what geography. However, the weighted average library connection cost is $60,000, approximately half the average school connection cost. This is because libraries are, on average, half the distance from an interconnection point.

Relative to schools, costs vary less by geography. Also libraries are less likely to be in rural areas than schools. For example:

- The Desert geography has the highest library fiber construction cost and represents approximately 2 percent of libraries that need fiber connections, but 9 percent of the total project cost. Each library will cost, on average, $260,000 to connect with fiber.

- In the Plains geography, each library will cost on average $55,000 to connect, much lower than a library in the same geography. Similar to the Desert geography, there are relatively few libraries (approximately 9 percent of the total). However more moderate construction cost (relative to schools) means that the libraries in this geography are 8 percent of the total project cost.

- The connection cost of the Metro area libraries ranges from $40,000 to $59,000, on average. This category comprises 63 percent of the libraries needing to be connected but approximately 55 percent of the project cost.

Table 17: Cost to Connect Libraries

Description	Dense Metro	Intermediate Metro	Low Density Metro	Rural Eastern Mountain	Rural Western	Desert	Plains	Rural Eastern
Libraries	4,029	3,848	3,170	921	535	342	1,561	3,041
Libraries without high speed data	3,425	3,271	2,695	783	455	291	1,327	2,585
Aerial cost per mile	$33,000	$33,000	$33,000	$32,000	$32,000	$32,000	$32,000	$32,000
Underground cost per mile*	$73,000	$57,000	$57,000	$88,000	$88,000	$51,000	$51,000	$51,000
Aerial percentage of miles	50%	50%	50%	90%	90%	75%	75%	50%
Underground percentage of miles	50%	50%	50%	10%	10%	25%	25%	50%
Last mile fiber miles per library not served	0.5	1.0	1.0	1.0	2.0	7.0	1.0	1.0
Last mile aerial miles per library not served	0.3	0.5	0.5	0.9	1.8	5.3	0.8	0.5
Last mile aerial cost per library not served	$8,000	$17,000	$17,000	$29,000	$58,000	$168,000	$24,000	$16,000
Last mile underground miles per library not served	0.3	0.5	0.5	0.1	0.2	1.8	0.3	0.5
Last mile underground cost per library not served	$18,000	$29,000	$29,000	$9,000	$18,000	$89,000	$13,000	$26,000
Last mile fiber cost per library	$26,000	$46,000	$46,000	$38,000	$76,000	$257,000	$37,000	$42,000
Drop and installation cost per library	$4,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000
Network electronics per library	$10,000	$10,000	$10,000	$15,000	$15,000	$15,000	$15,000	$15,000
Total cost per library	$40,000	$59,000	$59,000	$56,000	$94,000	$275,000	$55,000	$60,000

* Library Desert and Plains unit costs are higher than schools unit costs for those geographies, owing to clustering of libraries closer to towns

Appendix A: Metadata

The following metadata sources describe the filters underpinning the model's standardized geographies. 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 18: Metadata Sources

Geography	Metadata Source
United States	Esri U.S. States shapefile
Metro Areas	U.S. Census Urbanized Areas
Desert	EPA level I ecoregion classifications, excluding Metro Areas[14]
Plains	EPA level I ecoregion classifications, excluding Metro Areas and Desert[15]
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
Rural Eastern	Esri U.S. States shapefile, east of Plains, excluding previous categories

[14] "Ecoregions of North America: Level I Ecoregions," U.S. Environmental Protection Agency. Retrieved Oct. 8, 2014 from http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Level%20I.
[15] *Ibid.*