June 6, 2023

SUBMITTED ELECTRONICALLY VIA ECFS

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
45 L Street NE
Washington, DC 20554

Re: Ex Parte Filing
Establishing Emergency Connectivity Fund to Close the Homework Gap, WC Docket No. 21-93
Modernizing the E-Rate Program for Schools and Libraries, WC Docket No. 13-184

Dear Madam Secretary:

Pursuant to Federal Communications Commission's ex parte rules, I hereby submit the following summary of our June 2, 2023, conversation with Sue McNeil, Associate Bureau Chief, Wireline Competition Bureau (WCB) and Johnnay Schrieber, Deputy Division Chief, Telecommunications Access Policy Division, WCB. The following individuals participated in the call along with the undersigned: Reg Leichty, Foresight Law + Policy, PLLC; Bob Bocher, American Library Association (ALA); Megan Janicki, ALA; and John Windhausen, Jr., SHLB Coalition.

The participants on the call expressed strong interest in working with the FCC to incorporate lessons learned from the Emergency Connectivity Fund (ECF) Program into the E-rate program. As part of an inquiry about such lessons learned, we encourage the FCC to consider the following topics:

Hot spots and other alternative technologies: Many schools and libraries received ECF funding for devices like hot spots, which often provide valuable connectivity to households in need. In many areas, however, the applicants found that the cellular signal is often not strong enough to provide high-quality connectivity through hot spots, and hot spots only provide short-term connectivity solutions. SHLB thus encourages the FCC to also allow funding of other technological solutions that could provide reliable, long-term connectivity. For example, schools and libraries should be able to use CBRS-based wireless technologies, Wi-Fi mesh networks, TV white spaces, or other technology where viable, to connect students and patrons at home.[1] In

[1] For example, the ALA states that "[w]hile libraries are and will continue to loan hotspots and devices, as we noted in our previous filings, libraries are also connecting unconnected patrons through use of TV white spaces and boosting Wi-Fi signals, among other solutions." *See* Reply Comments of the American Library Association, *The*

August of 2020, SHLB and the Open Technology Institute at New America (OTI) released a study by Dr. Raul Katz demonstrating the economic feasibility of deploying wireless network extensions from an anchor institution to residences in a surrounding community.[2] Such networks could be significantly less costly than paying for hot spots largely because the consumers do not have to pay a monthly subscription fee as they do with hot spots. Funding the deployment of these network facilities rather than hot spots could reduce the impact of these costs on the Universal Service Fund (USF). A copy of that study is included as Attachment A. In tandem with Dr. Katz's study, SHLB and OTI released a companion paper highlighting twelve case studies that describe variations of anchor-enabled broadband networks across multiple states.[3]

Funding flexibility: Schools deserve regulatory funding flexibility because they are often faced with some of the hardest challenges. During the COVID-19 pandemic, CoSN conducted a study about the student experience during virtual learning. Among other lessons, we learned that for kids to learn at home they must have broadband capacity to deliver video capacity. Additionally, although students may have had capable broadband, they had insufficient routers at home. A copy of that study is included as Attachment B.

End-user devices: Devices like tablets were funded under the ECF Program, and ALA encourages the FCC to make such devices also available under the E-rate Program. Additionally, the ECF Program required libraries to comply with certain administrative demands that were often burdensome (such as rules around record retention and device lending). ALA encourages the FCC to consider removing or making such requirements less burdensome if incorporated into the E-rate Program.

Waiver of Cost-Allocation Rule: SHLB, CoSN, ALA and other parties filed a petition in January of 2021 prior to enactment of the ECF Program legislation.[4] We requested that the FCC waive the cost allocation rule so that entities can build off of E-rate funded fiber networks to extend service to the surrounding community without the school or library losing E-rate

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Emergency Connectivity Fund for Educational Connections and Devices to Address the Homework Gap during the Pandemic, WC Docket No. 21-93, 4-5 (Apr. 23, 2021), https://www.fcc.gov/ecfs/document/10423006759114/1.

[2] Dr. Raul Katz, *The "To and Through" Opportunity: An Economic Analysis of Options to Extend Affordable Broadband to Students and Households via Anchor Institutions*, THE SCHOOLS, HEALTH & LIBRARIES BROADBAND COALITION & THE WIRELESS FUTURE PROJECT AT THE OPEN TECHNOLOGY INSTITUTE AT NEW AMERICA (Aug. 2022), https://www.shlb.org/uploads/Policy/Policy%20Research/Off-Campus-Deployment-Economic-Assessment-final.pdf.

[3] Matthew Marcus and Michael Calabrese, *The "To and Through" Opportunity: Case Studies of School and Community Networks Able to Close the Homework Gap for Good*, THE SCHOOLS, HEALTH & LIBRARIES BROADBAND COALITION & THE WIRELESS FUTURE PROJECT AT THE OPEN TECHNOLOGY INSTITUTE AT NEW AMERICA (Aug. 2022), https://www.shlb.org/uploads/Policy/Policy%20Research/Anchor-Nets-Case-Studies-final.pdf.

[4] SHLB, et. al Petition for Expedited Declaratory Ruling and Waivers Allowing the Use of E-rate Funds for Remote Learning During the Covid-19 Pandemic, *Modernizing the E-rate Program for Schools and Libraries*, WC Docket No. 13-184 (Jan. 26, 2021), https://www.fcc.gov/ecfs/search/search-filings/filing/101260036427898.

funding.[5] Under current practices, if a school/library allows some of its capacity to be used off-campus, the school/library must remove a portion of the cost of the fiber to the school/library from its E-rate application. This deters most schools and libraries from allowing the extensions of service to the residential community. Allowing schools and libraries to allow such extensions without losing any E-rate support would not cost any money directly out of the USF and would allow schools and libraries to help bridge the digital divide. For instance, in one example, a major foundation proposed to deploy wireless service from a school on one side of the street to a low-income housing complex across the street, but the school refused to allow the interconnection to its fiber due to a concern that it would lose funding.

"Category 3" funding: If the E-rate Program funds broadband connectivity to the home, we strongly urge the FCC to consider creating a "Category 3" funding mechanism so that funds are not removed from Category 1 or 2.

Pace of Approvals: We encourage the FCC to consider concerns about the pace of approvals applicants may have experienced under the ECF Program and look for ways to improve the process going forward.

Sincerely,

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Megan Janicki
John Windhausen, Jr.

[5] *See also* Comments of the American Library Association, *The Emergency Connectivity Fund for Educational Connections and Devices to Address the Homework Gap during the Pandemic*, WC Docket No. 21-93, 5-6 (Apr. 5, 2021), https://www.fcc.gov/ecfs/document/10405314108601/1, stating "[i]t is important to note that with some of these technologies [e.g., TVWS] the remote connectivity will be backhauled to the library's own network. In such instances, it is essential that the bandwidth needed to support the connection from the library to its internet provider not be subject to any cost allocation based on the off-campus use of the library's bandwidth."

ATTACHMENT A

The "To and Through" Opportunity: An Economic Analysis of Options to Extend Affordable Broadband to Students and Households via Anchor Institutions

See Attached Economic Report

AUGUST 2022

THE "TO AND THROUGH" OPPORTUNITY:

An Economic Analysis of Options to Extend Affordable Broadband to Students and Households via Anchor Institutions

Economic analysis, Cost Calculation Toolkit and Public Policy Implications

By Dr. Raul Katz
Telecom Advisory Services LLC

SHLB
SCHOOLS, HEALTH & LIBRARIES BROADBAND COALITION

OPEN TECHNOLOGY INSTITUTE

About the Author

Raul Katz is president of Telecom Advisory Services LLC and director of business strategy research at the Columbia Institute for Tele-Information (Columbia Business School). Prior to founding Telecom Advisory Services, he worked for 20 years at Booz Allen & Hamilton where he led the telecommunications practices in North America and Latin America. He holds a Ph.D. in management science and political science, an M.S. in communications technology and policy from the Massachusetts Institute of Technology, and a Licence and Maitrise in communications sciences from the University of Paris.

About the Open Technology Institute at New America

The Wireless Future Project is part of the Open Technology Institute (OTI) at New America. New America is a nonprofit policy institute dedicated to renewing the promise of our nation's highest ideals, honestly confronting the challenges caused by rapid technological and social change, and seizing the opportunities those changes create. OTI and Wireless Future work at the intersection of technology and policy to promote universal access to communications technologies that are both open and secure, including wireless spectrum policies that encourage more ubiquitous, high-capacity and affordable wireless broadband connectivity for all Americans. Learn more at **www.newamerica.org/oti**.

About the Schools, Health & Libraries Broadband Coalition

The Schools, Health & Libraries Broadband (SHLB) Coalition is a nonprofit, 501(c)(3) public interest organization that supports open, affordable, high-quality broadband connections for anchor institutions and their surrounding communities. The SHLB Coalition is based in Washington, D.C. and has a diverse membership of commercial and non-commercial organizations from across the United States. To learn more, visit **www.shlb.org**.

Dear Supporters:

In early 2021, the Schools, Health & Libraries Broadband (SHLB) Coalition, the Wireless Future Project at New America, and other advocates jointly **petitioned** the Federal Communications Commission to allow off-campus use of E-Rate-funded services. We knew an estimated 15 to 17 million students were cut off from remote learning during the pandemic, and that many schools and libraries wanted to use their E-Rate funding to help connect these households to affordable broadband.

Congress recognized this opportunity by creating the Emergency Connectivity Fund (ECF) in the spring of 2021, a $7.17 billion program to allow schools and libraries to connect students and patrons to internet or devices. The ECF appeared to endorse SHLB's **"To-and-Through"** philosophy, which promotes leveraging anchor institution broadband to connect the surrounding community to "the internet".

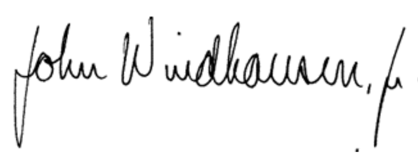
Unfortunately, the ECF program rules were limited primarily to purchasing monthly internet subscriptions, such as mobile carrier hotspots. Some internet service providers argued that building networks to-and-through schools and libraries to connect students would not be cost-effective and would deplete ECF funding too quickly. To determine whether this concern holds any weight, SHLB and Open Technology Institute (OTI) contracted with Dr. Raul Katz, president of Telecom Advisory Services, who conducted an economic analysis of off-campus wireless broadband deployment options.

The following report contains Dr. Katz's extensive economic assessment of the several options for anchor-led wireless broadband deployments. **In short, his research finds that deploying new wireless network connections to-and-through anchor institutions can often be the most low-cost and financially sustainable option to connect households in unserved and underserved areas.**

Anchor-enabled wireless networks can take many forms, which is why alongside this study we are publishing a collection of case studies of school districts successfully using different deployment models and wireless technologies on free-to-use spectrum. Dr. Katz has also created an interactive off-campus deployment toolkit, so that anchor institutions considering their own to-and-through projects can compare alternative solutions and figure out which approach makes sense for their communities' unique needs.

With the historic broadband programs in the Infrastructure Investment and Jobs Act being implemented, these materials provide a key revelation for policymakers, and anyone interested in permanently closing the "homework gap" and addressing the digital divide: To make the most of this broadband opportunity, we must build broadband to-and-through anchor institutions.

Michael Calabrese
Director, Wireless Futures Project
Open Technology Institute at New America



John Windhausen, Jr.
Executive Director
Schools, Health & Libraries Broadband (SHLB) Coalition

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EXECUTIVE SUMMARY

The purpose of this study is to develop an economic assessment of options that would allow anchor institutions[1] to serve as a hub from which to deploy wireless broadband services to users (students and their families) off-campus. When considering this opportunity, an anchor institution needs to, first and foremost, decide who the target customers will be: K-12 students only? K-20 students (which implies cooperation among schools and higher education)? Library patrons and unserved households? Once this decision is made, the institution faces a set of structural and technology decisions. The structural decision entails considering the entity responsible for service provisioning.

Three options are available:

- Acquire wireless broadband modems (hotspots) and purchase a commercial wireless plan (or a fixed wireline plan) for each user.
- Structure a public-private partnership with a Wireless Internet Service Provider (WISP) who takes on the responsibility for building and operating the off-campus network.
- Extend the existing anchor institution's network beyond the campus and offer service directly to students and/or the surrounding community.

The technology decision entails relying on either Citizens Broadband Radio System (CBRS) spectrum, Educational Broadband Service (EBS) bands if available, unlicensed Wi-Fi spectrum, or a combination of the above.

The study compares the economics of each potential option with two objectives:

- Determine whether the partnering or self-provision options are economically advantageous relative to purchasing service from a commercial service operator.
- Help anchor institutions decide which option is most advantageous from an economic standpoint.

It is based on models that quantify the investment and operating expenses of each option over an initial five-year period, demonstrating trade-offs and relative economic advantage. As such, the models provide the means to determine what is the most optimal way to fulfill the connectivity needs (see table A). Table A presents the economics calculated to serve a community of 19,000 users. It is based on models developed based on real-life experiences such as the Fresno Unified School District, "Connect2Learn" (Fresno, CA) and the East Side Union High School District (San Jose, CA).

[1] The term "anchor institutions" includes schools, libraries, healthcare providers, community colleges, public media, public housing, and other community organizations.

Table A : Economic comparison of off-campus wireless broadband provisioning option to serve a community of 19,000 users

	CAPEX	OPEX (ANNUAL)	NPV (OVER 5 YEARS)	COMMENTS
1. Purchase public LTE service from a commercial service provider	$ 4,465,000	$ 10,260,000 - $ 6,840,000	$ (46,770,000) - $ (32,688,00)	• CAPEX is based on acquiring wireless broadband Mi-Fi equipment • OPEX ranges are driven by alternative wireless plans (from $ 45 to $30) • Financials are calculated at full price, without considering any potential discounts and /or social responsibility offers
2. Contract a CBRS based WISP	$ 871,175	$ 248,000 - $ 227,000	$ (4,334,756)	• Reimbursement from WISP to anchor institution increases over time with commercial service penetration
3. Leverage CBRS spectrum to deploy an LTE private network (insource O&M)	$ 3,027,086	$ 206,327	$ (4,728,587)	• Financials exclude other “soft” costs of self-provisioning such as insurance, staff training, administrative overhead, and any regulatory/legal costs to
4. Leverage CBRS spectrum to deploy an LTE private network (outsource O&M)	$ 3,027,086	$ 412,300	$ (6,429,468)	
5. Contract with a third-party integrator to deploy and operate the Wi-Fi network	$ 899,824	$ 742,000	$ (7,015,000)	
6. Hybrid (Private LTE insource + Wi-Fi)	$ 2,215,000	$ 577,000	$ (6,974,000)	• Assumes 50/50 service split between both networks

NOTE: All NPVs are negative because, since there is no revenue charged for service, cashflows are always negative. In the only case where revenues are collected it is from reimbursement from leveraging network to offer commercial services in public-private partnership case.
Source: Telecom Advisory Services analysis

In short, as the table above indicates, **the indefinite purchase of monthly service through a commercial ISP is less cost-effective and financially sustainable than the other deployment options where they are feasible.** If, for example, a school district determines that commercial service provisioning (option 1) is not viable (e.g., because of low indoor signal quality considerations or budget constraints), the anchor institution faces one of the other four options.

The conclusions in this regard are clear:

- If the objective is to serve 19,000 users, most of them located in a high-density geography, where access points (APs) can be installed in municipality streetlights and traffic signals, contracting with a third-party integrator to deploy and operate a mesh Wi-Fi network (option 5) presents the lowest initial cost of deployment (CAPEX). However, ongoing operating costs (OPEX) can be significantly increased by the cost of supplying commercial data service to students within the coverage area who cannot receive a reliable connection from the network since this is contingent on the pricing of commercial service. That being said, if the number of users uncovered by the anchor institution network is a small share of the targeted student households (e.g., 1,000 out of 19,000 is assumed in this model), the OPEX declines significantly. In other words, a highly dense user community and a willingness by the municipality or local utility to provide free or subsidized access to vertical assets and backhaul makes a Wi-Fi network a very appropriate option to consider. Furthermore, considering that Wi-Fi unlicensed spectrum allocations could include the 6 GHz band in addition to 2.4 GHz and 5 GHz (per the FCC's April 2020 decision), the capacity and throughput per access point will be significantly enhanced, which might result in improved deployment economics.[2]
- While CAPEX of private CBRS-enabled LTE networks (option 3) is higher ($ 3,027,086) than mesh Wi-Fi (option 5) ($ 899,824), ongoing costs, even if O&M is outsourced (option 4) are quite advantageous for CBRS (because of the cost of supporting users not served by Wi-Fi). Furthermore, the primary benefit of CBRS use is related to the opportunity to serve exurban and other communities with low density that are located in geographies not particularly convenient for large Wi-Fi networks (which require a far greater number of APs).
- Furthermore, entailing a public-private partnership that leverages CBRS spectrum (option 2) is more advantageous in terms of CAPEX upfront costs and ongoing OPEX when compared to similar network configuration within a self-provision arrangement.

Finally, this study includes an interactive off-campus deployment toolkit, so that schools and libraries considering their own to-and-through projects can enter the variables that correspond to their local goals and situation, compare the cost of alternative solutions, and generate data that will help them determine which approach makes sense for their district's or community's unique needs. This interactive toolkit will be made available online by both SHLB Coalition and OTI/New America in the early fall 2022.

[2] See Katz, R., Jung, J. and Callorda, F. The economic value of Wi-Fi: a global view (2021-2025). A report for the Wi-Fi Alliance. New York: Telecom Advisory Services. Retrieved from: wi.fi.org; and Katz, R. (2020). Assessing the economic value of unlicensed use in the 5.9 GHz and 6 GHz bands. Washington, DC: Wi-Fi Forward. Retrieved from: wififorward.org/resources.

I. INTRODUCTION

One of the key components of SHLB's mission is "to build broadband **to and through**," which entails deploying the technology from anchor institutions to surrounding communities. This concept has been endorsed over the years through the Educational Broadband Services (EBS) rules and, more recently, supported by the Emergency Connectivity Fund (ECF), which provided funding of $7.17 billion to support schools and libraries to offer broadband service. In addition to funding the purchase of laptops, tablets, Wi-Fi hotspots, modems, and routers, the program allows schools and libraries to deploy networks off-campus to serve students, school staff and library patrons under certain circumstances. This is the first time that Congress has provided funding and allowed schools and libraries to provide service off-campus. However, a key condition established by the program for off-campus network deployment is that the institutions need to demonstrate that there are "no available service options sufficient to support remote learning." In establishing ECF reimbursement rules, the Federal Communications Commission's primary rationale for restricting eligibility for network deployments was "to reduce the risk of using emergency funding on time-consuming infrastructure construction projects."

This study provides an alternative view that **deployment of wireless broadband from an anchor institution to the community may, in some cases, may be not only economically rational but in some cases the most cost-effective and financially sustainable option.** The economic advantage of wireless broadband is not only based on lower cost to design, build and maintain a network. The faster speed of deployment has an implication in terms of the time value of benefit to the community. In other words, deploying connections to students at home can be the most financially sustainable way to close the homework gap quickly.

In addition, the purpose of this study is to develop an economic assessment of options that would allow anchor institutions to serve as a hub from which to deploy wireless connectivity to all users (including students, library patrons, and unserved/underserved households) off-campus. A set of case studies released at the same time as this study describe a variety of approaches that can help in making this option very cost-effective, including partnerships with private Internet Service Providers (ISPs) and with municipal or county governments. Six facts would indicate that off-campus service provisioning can be advantageous from a social and economic standpoint:

- There is significant activity on the part of an increasing number of anchor institutions in self-deploying private LTE networks leveraging the CBRS spectrum. They include school districts in Dallas, Fort Worth, and Castleberry, Texas; the Fresno, Fontana, and Patterson Unified School Districts in California; the Boulder Valley School District in Colorado; Utah Education and Telehealth Network; Harris County, Texas; Collinsville Community Unit School District #10; and DigitalC in Cleveland, among many others.

- Some other school districts have deployed extensive networks that connect most K-12 students without internet access using mesh or point-to-multipoint Wi-Fi deployments, typically in partnership with their municipality. These include the Council Bluffs Community School District in Iowa, San Jose, California's East Side Union High School District, and Lindsay Unified School District in California.
- Some school districts, libraries and local governments have stated that they reached the decision to self-deploy because the commercial option was not adequate considering the need to respond to the needs triggered by the pandemic, or because they wanted a more financially sustainable solution to close the homework gap permanently. Reasons they offered for pursuing the self-deployment route included "not a strong enough wireless signal" or "limited coverage" in many areas, particularly low-income and less densely populated geographies.
- There is an expanding ecosystem of private companies, including Nokia, Netsync, Cambium, Commscope, Kajeet, local Wireless Internet Service Providers (WISPs), and AWS, that are interested in supporting off-campus deployment.
- In addition, just as E-Rate has been expanded to help schools extend connectivity to every classroom using Wi-Fi, there are pending proposals to expand E-Rate funding and flexibility to include sustainable connectivity solutions to close the homework gap.
- In its current formulation, ECF is a one-time appropriation. If funding were to be extended in the future (which appears to be possible), the off-campus condition could be amended. **This paper also suggests that E-Rate networks can be used as backhaul for anchor community networks and that the economic rationale can justify other funding sources like bonds, taxes, etc.**

As a precedent, the off-campus restriction flies in the face of the FCC 2014 decision allowing schools and libraries to deploy dark fiber. Contrary to the original concern that fiber deployment would have a negative impact on the E-Rate program, the initiative generated savings which allowed E-Rate funding demands to decrease. For all of these reasons, self-deployment should be an option to be objectively considered in any economic assessment.

II. APPROACH FOLLOWED FOR ECONOMIC ANALYSIS

II.1. OVERALL METHODOLOGY

When considering the deployment of wireless broadband services to users off-campus, a school district or other anchor institution needs to, first and foremost, decide who the target customers will be: K-12 students, K-20 students (which implies cooperation among schools and higher education), library patrons, and/or all unserved or underserved households and families.[3] Once this decision is made, the institution faces a set of structural and technology decisions. The structural decision entails considering the entity responsible for service provisioning. Three options are available:

- Purchase service from a commercial wireless service provider: acquire wireless broadband modems and purchase a wireless plan for each user.
- Contract or partner with a non-traditional service provider to deploy wireless network facilities from the anchor institution to the community: structure a public-private partnership with a WISP or network integrator who takes on the responsibility for building and operating the off-campus network.
- Self-provision using the anchor institution's own personnel and infrastructure: Contract with private firms to extend the existing network beyond the campus and offer service to the surrounding community, maintaining ownership and operational control of the network.

The technology decision entails selecting the type of wireless network and the spectrum band to be relied upon (EBS, CBRS, or unlicensed Wi-Fi). In some cases, the structural choice pre-determines the technology option. For example, if the institution choses to purchase service from a commercial service provider, it will most likely rely on a commercial LTE (or even 5G) network. In other cases, many options are available (see Table II-1).

[3] Research indicates that students' success is not only driven by their own ability to connect but also when their families are connected.

Table II-1. Structural and technology options

TECHNOLOGY OPTIONS / STRUCTURAL OPTIONS	PURCHASE SERVICE FROM A COMMERCIAL WIRELESS SERVICE PROVIDER	CONTRACT OR PARTNER WITH A NON-TRADITIONAL SERVICE PROVIDER	SELF-PROVISION
LTE	Purchase public LTE service from a commercial service provider		
CBRS		Contract a CBRS based WISP	Leverage CBRS spectrum to deploy an LTE private network
EBS		Contract an EBS based WISP	Use EBS Spectrum
White Space			Use TV White spaces
Wi-Fi		Contract a Wi-Fi based WISP	• Deploy a mesh Wi-Fi network relying on unlicensed spectrum • Contract with a third party integrator to deploy and operate the network

Source: Telecom Advisory Services analysis

All school districts and other public institutions we have identified choose among several wireless technologies that all rely on free public access to spectrum. This greatly reduces costs compared to a commercial mobile service that relies on exclusively licensed spectrum purchased at auction. In some cases, the choice of a particular option is somewhat constrained by spectrum availability. For example, a county education authority or school system may have FCC licenses for free use of EBS spectrum (which was licensed decades ago for nonprofit educational purposes), but the spectrum is no longer available because of a past an agreement to lease the EBS spectrum originally assigned to a commercial operator, and the latter wishes to continue relying on this band for its own service. In this case, the possibility of self-provisioning service based on EBS spectrum has been foreclosed—and, indeed, most EBS spectrum has been leased out to commercial ISPs.

In other cases, certain topographic or population density conditions pre-ordain the need to select a subset of the options outlined in Table II-1. For example, because Wi-Fi operates on unlicensed spectrum that is high capacity but restricted to low power transmissions, mesh Wi-Fi networks are particularly suited to high density population concentrated in flat terrains. Alternatively, if the population to be served is located around an airport, the possibility of deploying institution-owned LTE towers might be precluded because the construction of high towers might be restricted.

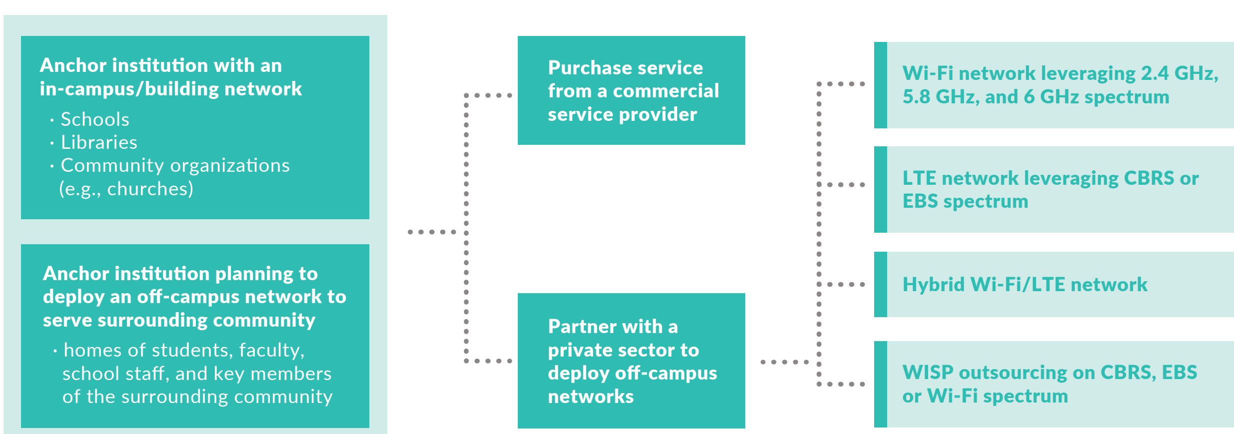
Further, the final decision on wireless technology or the scope of a deployment can, in some cases, entail a combination of two options. For example, if the owned network cannot fulfill the full coverage of the target community, the anchor institution might choose to purchase service from a commercial provider to complete the footprint. Similarly, if the community is distributed within highly concentrated clusters in combination with isolated residences, private LTE using CBRS spectrum and Wi-Fi networks relying on unlicensed spectrum might be advisable. A notable example of this hybrid configuration is the Lindsay Unified School District, in California's Central Valley, which leverages all three wireless technologies (Wi-Fi, CBRS, and EBS) to balance capacity and complete coverage of its low-income district, which varies enormously in terms of population density.

Recognizing these factors, the following study is focused on comparing the economics of each potential option with two objectives:

- Determine whether the partnering or self-provision options are economically advantageous relative to purchasing monthly subscription service from a commercial service operator.
- Help anchor institutions decide which option is most advantageous from an economic standpoint.

The study main deliverable is a set of economic models that provide the quantitative evidence in support of the options raised above (see Figure II-1).

Figure II-1. Economic model: Conceptual Map



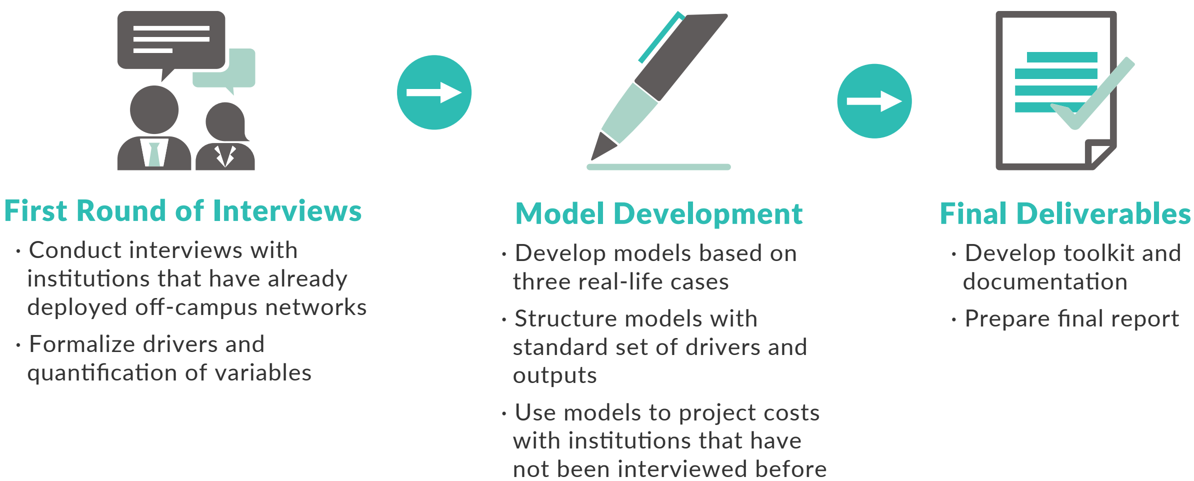
Source: Telecom Advisory Services analysis

Each of the five models quantifies the investment and operating expenses of each option, demonstrating trade-offs and relative economic advantage. As such, they provide the means to determine what is the better way to fulfill the connectivity needs: Acquisition from a commercial service provider? Self-deployment? Public-private partnership? Which technology? In this context, the models can also be used as a toolkit (provided under separate cover) for institutions to evaluate the best options for deployment from an economic standpoint (what are the factors to be considered in selecting an option: Access to buildings or streetlights? Access to backhaul? Access to other vertical assets? Population density?).

II.2. APPROACH FOLLOWED FOR ECONOMIC MODEL DEVELOPMENT

The approach followed for the development of economic models was structured around three phases (see Figure II-2).

Figure II-2. Study approach



Source: Telecom Advisory Services analysis

We started the project by interviewing institutions that have deployed networks to confirm a set of working hypotheses and drivers of the costs and flow of benefits to different parties of a model that extends to off-campus. In addition, we conducted interviews of vendors (equipment and systems integrators) to gain access to capital and operating expenditure information from case studies. For this purpose, we selected key cases that match each of the options mentioned above and could generate enough data to build a model, conceived as an "ideal type," that captures the economics of each option (see Table II-2).

Table II-2. Interviews conducted

MODEL	EXPERIENCE	INTERVIEWS (AND NUMBER OF INTERACTIONS)
LTE CBRS	Fresno Unified School District, "Connect2Learn" (Fresno, CA)	Phil Neufeld (3)
Mesh Wi-Fi (by contracting with third party integrator)	East Side Union High School District (San Jose, CA)	Randy Phelps (2) Al Brown (2)
WISP services leveraging Mesh Wi-Fi	Sherman Independent School District (Sherman, TX)	JJ McGrath
WISP services leveraging CBRS spectrum	"ConnectME" Boulder Valley School District (Boulder, CO)	Andrew Moore
Hybrid CBRS/EBS/Mesh Wi-Fi	Lindsay Unified School District (Tulare County, CA)	Peter Sonksen (2)
TV White Space	Dallas School District	Mike Houston

Source: Telecom Advisory Services analysis

Each set of interviews and following data requests allowed the development of a model that captures the economics of a specific case. The model captures key drivers—number of users, all capital expenditures, and operating expenses if they were to extend their infrastructure to serve the homes of students, faculty, school staff, and key members of the surrounding community. The Fresno Unified School District was selected to reflect an LTE CBRS "pure play," the East Side Union School District as a mesh Wi-Fi "pure play," the Boulder Valley School District for public-private partnership with a WISP for a CBRS-based network, while the Lindsay School District represents a hybrid network built around CBRS/EBS/mesh Wi-Fi technologies.

However, for the models to be integrated within a unified toolkit (in other words, being able to be compared apples-to-apples), the "real life" economic models were modified in several dimensions:

- **Consider only one of the potentially many project phases:** Many of the studied networks were built out through many implementation phases, reflecting multiple cycles of grants and budget allocations. Since these may even be based on different cost structures (pricing lists, potential discounts), we decided to consider only one phase to model standardized costs.
- **Avoid equipment refreshments:** In some cases, a particular network underwent successive equipment updates to replace prematurely obsolete generations. We excluded any refreshments, thereby assuming that equipment had at least a lifetime of five years (an assumption validated through interviews).

- **Use interview or price sheet data:** In some cases, the price of equipment is based on specific vendor conditions (e.g., discounts, promotions); for comparability purpose, we relied only on list price data.
- **Model project CAPEX as a one-time event:** While CAPEX could be modified for network fine-tuning or modernization, we opted to calculate all models based on an initial CAPEX outlay taking place in year 1.
- **Model OPEX over five years:** For comparability purposes, each model calculates the Net Present Value (NPV) at a uniform discount rate (5 percent). Since no revenues were considered in the models[4], the NPVs are all presented with a negative sign. Further, the NPV calculation is a function of the number of years considered as operational. Again, for comparability process, we chose to consider five years of operation (rather than a conventional ten year used for financial analysis).

Once each model was standardized, it was integrated in a single set of spreadsheets, called the toolkit, organized in the following way (see Figure II-3).

Figure II-3: Toolkit model structure (example)

Key Drivers

- Projected user population (schools, students, households)
- Geographic deployment (km²)
- Topography
- Population density
- Estimated usage per device (smartphones, tablet, wireless modems)
- Devices provided to users (PC, tablets, netbooks, routers, wireless modems)
- Access to vertical assets (cell towers, water towers)
- Access to subsidized siting (buildings, lamp-posts, etc.)
- Access to subsidized backhaul or passive infrastructure
- Partnership opportunities (WISP, commercial service provider, municipality, device/equipment mfrg)
- Service level targets (speeds, throttle conditions)

Private LTE Mesh Wi-Fi Hybrid LTE/Wi-Fi & Commercial Carrier Calculations

- Network Eqipment
- Total CAPEX (Fiber/wiring to the APs/towers, APs, civil engineering, RF engineering
- Initial CAPEX (site infrastructure, equipment)
- CPE costs
- Deployment costs
- Backhaul costs
- OPEX (operations, maintenance)

Model Comparison (comparative results of the three options)

- Financials
  - Internal Rate of Return
  - NPV (with and without terminal value)
- Service quality
- Social impact
  - Adoption
  - Use
- Economics

Source: Telecom Advisory Services analysis

The toolkit structure and instructions for using it are included in Appendix A.

[4] In one case, the public-private partnership for CBRS deployment, the anchor institution receives a revenue contribution from the WISP partner. In this case, the contribution was considered in terms of an OPEX reduction.

III. PRESENTATION OF RESULTS

The following section presents the results of the economic analysis of each option as generated in the toolkit. All models are calculated based on a common set of drivers.

III.1. MODEL DRIVERS

To enable an economic comparison across structural and technology options, the following drivers[5] are defined in the toolkit to apply, once set, to all four options (see Table III-2). These drivers impact the economics of each option.

Table III-2. Economic model drivers assumed in model

	DRIVER	
DEPLOYMENT CONDITIONS	Is the network going to serve students only or a community?	Community
	What are the service quality level of commercial carriers?	Low
	Is the projected network near airports or defense facilities?	Yes
	Does the anchor institution have access to EBS spectrum?	No
	Does the projected network have access to city poles (such as streetlights)	Yes
	If yes, is access for free or at a certain rate?	Free
	Can schools serve as towers?	Yes
	Does the projected network have access to any other type of municipal vertical assets?	No
	Is that access to vertical assets subsidized?	Not Apply
	Is backhaul for the projected network supplied by school district	$1,000
	Is backhaul for the network provided by municipality?	No
	If yes, is cost allocated based on E-Rate use?	Yes
	Are there any issues/concerns regarding CPE in-door installation?	Yes
NETWORK REQUIREMENTS	Coverage area (sq. miles)	0
	Topography	Flat
	Vegetation	Varies
	Structures	Varied
	Population density	
	Number of schools in district	18
	Number of households	20,000
	Average building height	Single Floor
	Student population	22,576
	Single family/multi-dwelling breakdown	
	Percent students targeted by the network	75%
	Percent disadvantaged	60%
	Number of students that have internet access at home	50%
	Number of schools connected	3
	Estimated usage per device	Uncapped
	Number of devices to be distributed to users	
SERVICE LEVEL REQUIREMENTS	Number of simultaneous users per school	35
	Number of devices running on the network	15,000
	Share of users in high density zone	50%
	Share of users in low density zone	50%
	Number of concurrent users	19,000
	Are users evenly distributed across coverage area	Yes
	Service level targets (speed)	20/20
	Service level targets (throttle conditions)	No

Source: Telecom Advisory Services analysis

[5] See detailed definition of drivers in the Appendix of this document.

III.2. PURCHASE LTE SERVICE FROM A COMMERCIAL WIRELESS SERVICE PROVIDER

The economic estimation of this option assumes that indoor signal quality in the geography of the targeted community is good. From an economic standpoint, it is based on assessing the costs if the anchor institution enters into a contract with a commercial wireless service operator to offer connectivity to the targeted population (19,000 users) in the surrounding community (see Table III-3).

Table III-3. Structural and technology options

TECHNOLOGY OPTIONS	STRUCTURAL OPTIONS: PURCHASE SERVICE FROM A COMMERCIAL WIRELESS SERVICE PROVIDER	STRUCTURAL OPTIONS: CONTRACT OR PARTNER WITH A NON-TRADITIONAL SERVICE PROVIDER	STRUCTURAL OPTIONS: SELF-PROVISION
LTE	Purchase public LTE service from a commercial service provider		
CBRS		Contract a CBRS based WISP	Leverage CBRS spectrum to deploy an LTE private network
EBS		Contract an EBS based WISP	Use EBS Spectrum
White Space			Use TV White spaces
Wi-Fi		Contract a Wi-Fi based WISP	• Deploy a mesh Wi-Fi network relying on unlicensed spectrum • Contract with a third party integrator to deploy and operate the network

Source: Telecom Advisory Services analysis

It assumes that wireless data modems (hotspots) are purchased and paid upfront for a unit cost of $235[6], combined with a wireless data plan of $45 a month.[7] This results in an upfront cost of $4,465,000 (with activation fees) and a total annual outlay of $10,260,000.

[6] Verizon jetpack MIFI 8800L (Source: Verizon)
[7] 5G Play More Plan (Verizon) 50 GB then unlimited data at throttled down speed.

While lower-priced options exist in the marketplace, an offer was selected to reflect a service that matches closely the type of service to be delivered by the other self-provision offers.[8] Furthermore, the total cost does not assume a potential discount of the commercial pricing that the anchor institution might benefit from. For sensitivity purpose, the following table presents a comparison of economics for lower service levels (see Table III-4). In the table, CAPEX represents the cost of a MiFi hotspot (CPE), while OPEX is the ongoing monthly service cost.

Table III-4. Comparison of Alternative Commercial wireless service plans (19,000 users)

PLAN	WIRELESS MONTHLY PLAN	CAPEX (UPFRONT) (*)	OPEX (ANNUAL)
• Verizon jetpack MIFI 8800L • 5G Play More Plan 50 GB then unlimited data at throttled down speed	$ 45	$ 4,465,000	$ 10,260,000
• Verizon jetpack MIFI 8800L • 5G Start (5G/4G hotspot data 5GB then unlimited data at throttled down speed)	$ 40	$ 4,465,000	$ 9,120,000
• Verizon jetpack MIFI 8800L • Unlimited 5G (5G/4G hotspot data with throttled down speed at congestion times)	$ 30	$ 4,465,000	$ 6,840,000

(*) For modem payments

Source: Telecom Advisory Services analysis

As indicated in Table III-4, CAPEX under this option remains stable at $4,465,000, while OPEX ranges between $10,26,000 at the high end but can decrease to $6,684,000.

III.3. CONTRACT A CBRS BASED WISP PARTNERSHIP

The economic estimation of this option assumes that signal quality (average download and upload speed, latency) of commercial networks in the geography of the targeted community of the anchor institutions is not uniformly good, which requires the deployment of a new network. From an economic standpoint, this option is based on assessing the costs if the anchor institution enters into a contract with a WISP to deploy and operate a private LTE network in the CBRS spectrum band (see Table III-5).

[8] For reference, the One Million Project offers 10 GB of high-speed data per month. If data usage exceeds 10 GB in a given month, user will continue to receive unlimited data service at 2G speeds for the remainder of that month. A free wireless device is also provided although actual device type will depend on the school and availability.

Table III-5. Structural and technology options

TECHNOLOGY OPTIONS	STRUCTURAL OPTIONS: PURCHASE SERVICE FROM A COMMERCIAL WIRELESS SERVICE PROVIDER	CONTRACT OR PARTNER WITH A NON-TRADITIONAL SERVICE PROVIDER	SELF-PROVISION
LTE	Purchase public LTE service from a commercial service provider		
CBRS		Contract a CBRS based WISP	Leverage CBRS spectrum to deploy an LTE private network
EBS		Contract an EBS based WISP	Use EBS Spectrum
White Space			Use TV White spaces
Wi-Fi		Contract a Wi-Fi based WISP	• Deploy a mesh Wi-Fi network relying on unlicensed spectrum • Contract with a third party integrator to deploy and operate the network

Source: Telecom Advisory Services analysis

An example of such an arrangement is the public-private partnership entered between the Boulder Valley School District's (BVSD) and a small local WISP, Live Wire Networks, Inc. However, some changes were introduced in the BVSD model to make it comparable with the other options:

- The real-life model serves only 1,000 students at home. As indicated above, the toolkit models a community of 19,000 users. This required updating the number of targeted users.
- While student connections provided by BVSD are free at the lowest speed tier (minimum throughput speeds of 35/5 Mbps), households can pay for faster speed tiers for an additional $5 to $15 per month. As indicated above, no revenues are included in the calculation of the NPV.
- For student households that are not yet in network coverage, or for the students who live in more remote or mountainous areas, BVSD provides mobile carrier wireless modems. They also help families set up Comcast's Internet Essentials in areas where it is available and BVSD's network has yet to reach. Again, for comparability purpose, we assumed, based on CBRS propagation characteristics, that all 19,000 users would be within the CBRS network coverage.

- Certain cost categories (electricians, radio frequency planning, some CAPEX items) have been changed to reflect the values of the CBRS private network case (Fresno) for consistency purposes.

Beyond these modifications to the BVSD model, some cost items were kept similar to remain faithful to the conditions of the public-private partnership agreement:

- All sites were based on school buildings, so no investment is required for antenna deployment except for structural engineering for school mounts ($1,600 per site as per Fresno network); however, considering that the 1,000 students for the current 19 base stations in the BVSD case represents a low utilization ratio, the 360 students per site ratio from Fresno was used.
- Cost per site is $6,000 (much lower than the private LTE option because the WISP is expected to assume a portion of the cost).
- The WISP covers most of the installation costs, which includes construction, frames, conduits, and labor.
- The WISP is willing to shoulder a large share of the upfront capital investments given that the network will grow and gather more tenants and commercial customers for the ISP (the school owned CBRS base stations are also used to support traffic for the WISP commercial connections).
- While the school does not charge for the service, it receives a revenue reimbursement from the WISP of $600 per site in the first two years, increasing to $1,000 per site after that.
- Radio stations are backhauled using district-owned fiber but as a result the district loses E-Rate funding since it must allocate the CBRS network's portion of the cost avoid violating FCC rules that restrict E-Rate subsidies to on-campus connections.
- The school issues CPEs to students.
- Operating costs are equal to the in-sourced Fresno network.

As a result, key specific drivers for the CBRS based WISP partnership configuration are as follows (see Table III-6).

Table III-6. CBRS based WISP partnership specific drivers

	DRIVER	VALUE	SOURCE
NETWORK EQUIPMENT	Number of concurrent users per sector	120	Fresno case
	Number of sites	53	Calculated based on 19,000 users
	Number of sites where schools provide vertical access	53	Anchor Nets case studies
	Radio (per unit)	$ 6,000	Anchor Nets case studies
	Installation (per unit)	$ 0	Anchor Nets case studies
	RF Design (per unit)	$ 660	Fresno Ph. II price sheet
	LTE Evolved Packet Core + SAS server	$ 31,000	Fresno Pricing sheet
	Antenna, RF jumpers (per unit)	$ 1,437	Fresno Pricing sheet
DEPLOYMENT COSTS	RF design and Planning (total)	$ 34,833	$ 2,860 per site (Fresno)
	Installation (total)	$ 0	Anchor Nets case studies
	Remote services training (total)	$ 55,000	Fresno case
	Structural engineering for school mounts (total)	$ 84,444	Tester Architects and Engineers
	DSA inspector (total)	$ 20,056	$ 380 per site (Fresno)
	Electricians (total)	$ 253,000	Fresno Echo quote
BACK HAUL	Traffic requirements (Gbps)	$ 6,327	0.33 Mbps* concurrent users
	Cost of backhaul	$ 80,000	Fresno costs before ECF reimbursement

Source: Telecom Advisory Services analysis

The costs presented in Table III-6 reflect, beyond the modifications mentioned above, the partnership agreement signed between the BVSD and Livewire. It is important to mention, however, that public-private partnership agreements are case specific and therefore, costs might shift in each case. Finally, the model attractiveness is also contingent on the treatment of backhaul costs through E-Rate.

Based on these specific drivers, this option requires $871,000 in upfront CAPEX[9] and an annual OPEX ranging from $248,000 to $227,000 after reimbursements from WISP.

[9] The difference with the $264,000 CAPEX ConnectMe Boulder Valley School District is driven by the number of sites (19 in case vs. 53 estimated for 19,000 users) and a range of CAPEX assumed by the WISP in the case study while they were allocated to the anchor institution in the toolkit.

Table III-7. CBRS based WISP partnership financials

	ITEM	VALUE					
CAPEX	Radios	$ 316,667					
	LTE Evolved Packet Core	$ 31,000					
	Antennas, RF jumpers	$ 75,842					
	Total	$ 423,508					
DEPLOYMENT COSTS	RF design and Planning	$ 34,833					
	Installation	$ 0					
	Remote services training	$ 55,000					
	Structural engineering for school mounts	$ 84,444					
	DSA inspector	$ 36,944					
	Electricians	$ 738,889					
	TOTAL	$ 950,111					
ANNUAL OPEX	SW maintenance and Licenses	$ 150,000					
	Truck rolls to fix vertical assets	$ 50,000					
	Total	$ 200,000					
FINANCIALS		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
	Backhaul cost	$ 0	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 80,000
	Opex	$ 0	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
	Recurring costs	$ 0	$ 280,000	$ 280,000	$ 280,000	$ 280,000	$ 280,000
	Reimbursement	$ 0	$ 31,800	$ 31,800	$ 53,000	$ 53,000	$ 53,000
	OPEX-Reimbursements	$ 0	$ 248,200	$ 248,200	$ 227,000	$ 227,000	$ 227,000
	Capex	$ 871,175	$ 0	$ 0	$ 0	$ 0	$ 0

Source: Telecom Advisory Services analysis

III.4. LEVERAGE CBRS SPECTRUM TO DEPLOY AN LTE PRIVATE NETWORK

As in the prior model, the economic estimation of this option assumes that signal quality of commercial carriers in the geography of the targeted community is not good. However, contrary to the public-private partnership with a WISP, the anchor institution assumes responsibility to deploy and operate a private LTE network in the CBRS spectrum band, although it might choose to subcontract deployment and operations to a third-party integrator, which is in fact typical of the existing networks studied (see Table III-8).

Table III-8. Structural and technology options

TECHNOLOGY OPTIONS / STRUCTURAL OPTIONS	PURCHASE SERVICE FROM A COMMERCIAL WIRELESS SERVICE PROVIDER	CONTRACT OR PARTNER WITH A NON-TRADITIONAL SERVICE PROVIDER	SELF-PROVISION
LTE	Purchase public LTE service from a commercial service provider		
CBRS		Contract a CBRS based WISP	Leverage CBRS spectrum to deploy an LTE private network
EBS		Contract an EBS based WISP	Use EBS Spectrum
White Space			Use TV White spaces
Wi-Fi		Contract a Wi-Fi based WISP	• Deploy a mesh Wi-Fi network relying on unlicensed spectrum • Contract with a third party integrator to deploy and operate the network

Source: Telecom Advisory Services analysis

An example of such an arrangement is the Fresno Union School District, Connect2Learn (Fresno, Cali.). Some changes were introduced in the FUSD model to make it comparable with the other options:

- The model is based on the economics of Phase I only.
- We excluded any equipment refreshments, thereby assuming that equipment had at least a lifetime of five years.
- For equipment pricing, we relied only on list price data.

All remaining cost items were kept the same to remain faithful to the model:

- A portion of sites (17) were based on school buildings, while the remainder required deployment of antennas.
- Cost per base station is $26,000.
- The installation cost is $8,580 (33 percent of radio costs), while the RF design cost is $2,860 (11 percent of radio costs).
- The Nokia Evolved Packet Core (EPC) cost 31,000, while the antennas and RF jumpers totaled approximately $1,440 per unit, and CPE equipment ranged between $175 per unit for indoor Wi-Fi beacon units and $400 for outdoor CPEs for multi-dwelling housing.

- Costs for engineering, electricians, and inspectors were included in the budget (although this could become a swing factor in real-life).
- Backhaul costs were allocated through E-Rate.

As a result, the key specific drivers for the CBRS-based LTE private network configuration are as follows (see Table III-9).

Table III-9. CBRS-based LTE private network specific drivers

	DRIVER	VALUE	SOURCE
NETWORK EQUIPMENT	Number of concurrent users per sector	120	Fresno case
	Number of sites	53	Calculated based on 19,000 users
	Number of sites where schools provide vertical access	53	Anchor Nets case studies
	Number of sites where schools provide vertical access	17	Fresno case
	Base station cost (per unit)	$ 26,000	Fresno price sheet
	Installation cost (per unit)	$ 8,580	Fresno price sheet
	RF Design (per unit)	$ 2,680	Fresno Ph. II price sheet
	LTE Evolved Packet Core + SAS server	$ 31,000	Fresno Pricing sheet
	Antenna, RF jumpers (per unit)	$ 1,437	Fresno Pricing sheet
CPE EQUIPMENT	Single family (indoor) (per unit + SIM + sales tax)	$ 175	Fresno Pricing sheet
	Multi-dwelling (outdoor) (per unit + SIM + sales tax)	$ 400	Fresno Pricing sheet
	Multi-dwelling (indoor) (per unit + SIM + sales tax)	$ 76	Fresno Pricing sheet
	Installation (per household)[10]	$300	Fresno case
DEPLOYMENT COSTS	RF design and Planning (total)	$ 150,944	$ 2,860 per site (Fresno)
	Installation (total)	$ 448,611	Anchor Nets case studies
	Remote services training (total)	$ 55,000	Fresno case
	Structural engineering for school mounts (total)	$ 84,444	Tester Architects and Engineers
	DSA inspector (total)	$ 20,000	$ 380 per site (Fresno)
	Electricians (total)	$ 253,000	Fresno Echo quote[11]
BACKHAUL COSTS	Traffic requirements (Gbps)	$ 6,327	0.33 Mbps* concurrent users
	Cost of backhaul	$ 80,000	Fresno costs before ECF reimbursement
	E-Rate cost allocation	$ 6,327	

Source: Telecom Advisory Services analysis

[10] Fresno Unified only went with two use cases :1) indoor units Cradlepoint R500 and 2) backpackable unit SMC 411 (with ECF funds we'll be getting the Enseego MiFi 8000 from Kajeet). While recognizing that Db loss is less with an external antenna, it did not rely on external antennas given the cost per structure and the more mobile nature of the students/families.

[11] The final electrician cost was much higher in the Fresno case ($ 738,889) but that included AC power source, while 90% of LTE are constructed with DC power with inverters in the IDF/MDF and low voltage ethernet cable running to the external antenna.

Based on these specific drivers, the corresponding economics amount to $3,027,000 upfront CAPEX (composed of $2,015,000 in equipment and $1,012,000 in deployment costs) and an annual OPEX ranging from $206,000 (if insourced) and $413,000 (if outsourced)[12] (see Table III-10).

Table III-10. CBRS-based LTE private network financials

	ITEM	VALUE
CAPEX	Radios	$ 1,372,222
	LTE Evolved Packet Core	$ 31,000
	Antennas, RF jumpers	$ 227,525
	CPE-MiFi indoor single family	$ 288,750
	CPE-Outdoor Multi-dwelling	$ 80,000
	CPE-Indoor Multi-dwelling	$ 15,200
	Total	$ 2,014,697
DEPLOYMENT COSTS	RF design and Planning	$ 150,944
	Installation	$ 448,611
	Remote services training	$ 55,000
	Structural engineering for school mounts	$ 84,444
	DSA inspector	$ 20,056
	Electricians	$ 253,333
	TOTAL	$ 1,012,389
ANNUAL OPEX (IN SOURCE)	SW maintenance and Licenses	$ 150,000
	Truck rolls to fix vertical assets	$ 50,000
	Total	$ 200,000
ANNUAL OPEX (OUT SOURCE)	Annual maintenance for Nokia support and software updates	$ 351,852
	Field maintenance contract	$ 54,400

		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
FINANCIALS (IN SOURCE)	Backhaul cost	$ 0	$ 6,327	$ 6,327	$ 6,327	$ 6,327	$ 6,327
	Opex	$ 0	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
	Recurring costs	$ 0	$ 206,327	$ 206,327	$ 206,327	$ 206,327	$ 206,327
	Capex	$ 3,027,086	$ 0	$ 0	$ 0	$ 0	$ 0
FINANCIALS (OUT SOURCE)	Backhaul cost	$ 0	$ 6,327	$ 6,327	$ 6,327	$ 6,327	$ 6,327
	Opex	$ 0	$ 406,252	$ 406,252	$ 406,252	$ 406,252	$ 406,252
	Recurring costs	$ 0	$ 412,579	$ 412,579	$ 412,579	$ 412,579	$ 412,579
	Capex	$ 3,027,086	$ 0	$ 0	$ 0	$ 0	$ 0

Source: Telecom Advisory Services analysis

[12] These costs were calibrated/confirmed with Fresno case.

III.5. DEPLOY A MESH WI-FI NETWORK RELYING ON UNLICENSED SPECTRUM

The economic estimation of this option assumes that signal quality in the geography of the targeted community is not uniformly good but can nevertheless serve as a good complement to the Wi-Fi network in case of out-of-Wi-Fi coverage users. While the anchor institution assumes responsibility to deploy and operate the Wi-Fi network in the unlicensed spectrum bands, it chooses to subcontract deployment and operations to a third-party integrator (see Table III-11).

Table III-11. Structural and technology options

TECHNOLOGY OPTIONS / STRUCTURAL OPTIONS	PURCHASE SERVICE FROM A COMMERCIAL WIRELESS SERVICE PROVIDER	CONTRACT OR PARTNER WITH A NON-TRADITIONAL SERVICE PROVIDER	SELF-PROVISION
LTE	Purchase public LTE service from a commercial service provider		
CBRS		Contract a CBRS based WISP	Leverage CBRS spectrum to deploy an LTE private network
EBS		Contract an EBS based WISP	Use EBS Spectrum
White Space			Use TV White spaces
Wi-Fi		Contract a Wi-Fi based WISP	Deploy a mesh Wi-Fi network relying on unlicensed spectrum Contract with a third party integrator to deploy and operate the network

Source: Telecom Advisory Services analysis

An example of such an arrangement is the East Side Union High School District (ESUHSD) (San Jose, Cali.). Some changes were introduced in the ESUHSD model to make it comparable with the other options:

- The model is based on economics of Phase I deployment only (covering the James Lick High School, the Overfelt, and Yerba Buena attendance areas).
- We excluded any equipment refreshments, thereby assuming that equipment had at least a lifetime of five years (as mentioned in the case, the APs could have a lifespan of ten years).
- For equipment pricing, we relied only on list price data.
- While in ESUHSD the city provides fiber backhaul to the APs, it was assumed that backhaul would be included as part of OPEX.

All remaining cost items were kept similar to remain faithful to the model:

- All AP sites are mounted on streetlights and traffic lights, although the municipal permit fee per light pole to install a commercial AP is waived (a considerable saving), which also provides electricity to the sites.
- Cost per AP is $320, while installation (including all supporting infrastructure, materials, and services) amounts to $4,257 and other equipment (switches, PTP radios, PTMP radios) prorated by AP is $1,570.
- It was assumed that 1,000 out of the 19,000 students are not covered by the Wi-Fi network and therefore require commercial service coverage (this is an important assumption that can swing the economics significantly).
- RF design and planning for the network amounts to $333,000 (split between pre-project planning ($80,910) and wireless network planning and design ($251,906).

As a result, key specific drivers for the mesh Wi-Fi network configuration are as follows (see Table III-12).

Table III-12. Mesh Wi-Fi network specific drivers

	DRIVER	VALUE	SOURCE
NETWORK EQUIPMENT	Number of Access Points	600	San Jose interview
	Number of Access Points where schools provide vertical access	0	San Jose case
	Number of Access Points where municipality provides vertical access	600	San Jose case
	Access Point cost (per unit)	$ 320	Ruckus wireless
	Installation	$ 4,257.04	San Jose Smartwave contract
	Other equipment (switches, PTP radios, PTMP radios) per AP	$ 1,570.00	San Jose Smartwave contract
CPE EQUIP	Number of users that cannot access deployed infrastructure (data modems)	1,000	San Jose case
	Data modems (per unit)	$ 299.00	Verizon
DEPLOYMENT COSTS	RF design and Planning	$ 332,816	San Jose case
	Licenses	$ 15,000	San Jose interview
	Circuit tracing	$24,000	San Jose interview
	Structural analysis	$ 18,000	San Jose interview
	Luminaire photocell remediation	$ 48,000	San Jose interview
	Sales tax	$ 35,018	San Jose interview
	Total	$ 472,834	San Jose case
BACKHAUL COSTS	Point to point interconnection (fiber)	$ 120,000	San Jose case
	Traffic requirements (Gbps)	10	San Jose case
	Cost of backhaul	$ 80,000	Assumption
	Support per client per year	$ 2.61	San Jose interview

Source: Telecom Advisory Services analysis

Based on these specific drivers, the corresponding economics amount to $899,824 upfront CAPEX (composed of $426,990 in equipment and $472,834 in deployment costs) and an annual OPEX of $741,590 (see Table III-13).

Table III-13. Mesh Wi-Fi network financials

	ITEM	VALUE					
EQUIP-MENT	Access Points	$ 192,000					
	Wireless modems	$ 234,900					
	Total	$ 426,990					
DEPLOYMENT COSTS	RF design and Planning	$ 332,816					
	Licenses	$ 15,000					
	Circuit tracing	$ 24,000					
	Structural analysis	$ 18,000					
	Luminaire photocell remediation	$ 48,000					
	Sales tax	$ 35,018					
	Total	$ 472,834					
ANNUAL OPEX	Network Operations & Maintenance (insource)	$ 40,000					
	Network Operations & Maintenance (outsource)	$ 49,590					
	Customer service	$ 32,000					
	Modems data plans (unit cost)	$ 540,000					
	Total	$ 661,590					
FINANCIALS		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
	Backhaul cost	$ 0	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 80,000
	Opex	$ 0	$ 661,590	$ 661,590	$ 661,590	$ 661,590	$ 661,590
	Recurring costs	$ 0	$ 741,590	$ 741,590	$ 741,590	$ 741,590	$ 741,590
	Capex	$ 899,824	$ 0	$ 0	$ 0	$ 0	$ 0

Source: Telecom Advisory Services analysis

As in the private LTE case, these costs were calibrated/confirmed with the corresponding case (San Jose network).

III.6. OTHER REMAINING OPTIONS

The original framework of structural and technology options considered eight options, of which four were assessed in terms of their economics and were included in the toolkit:

- Purchase public LTE service from a commercial service provider
- Contract a CBRS based WISP
- Leverage CBRS spectrum to deploy an LTE private network
- Contract with a third-party integrator to deploy and operate the Wi-Fi network

Other four options were not analyzed because interviews and case study data indicated that they were less relevant or could be captured in the four that were analyzed:

- **Use Educational Broadband Service (EBS) Spectrum:** Many anchor institutions found, when considering options, that this spectrum was not available since it had been previously leased by them to wireless operators (such are the cases in the Fresno USD and the Val Verde USD). While the Imperial County Board of Education and Northern Michigan University rely on EBS spectrum, the characteristics of their networks are fairly specific to both institutions. Finally, the Lindsay Unified School District (LUSD) relies on EBS spectrum within a hybrid network configuration which also includes the use of Wi-Fi and CBRS spectrum.
- **Use TV White Spaces:** While the TV White spaces spectrum can extend the reach and penetration of wireless connections due to its propagation characteristics, deployments tend to be fairly small. For example, the North Carolina Dept. of Public Instruction serves only 24 connections.
- **Contract a Wi-Fi based WISP:** This option is similar in terms of economics to the Contract with a third-party integrator to deploy and operate the CBRS-LTE network.
- **Deploy an institution-owned mesh Wi-Fi network relying on unlicensed spectrum:** The option is similar in terms of economics to the Contract with a third-party integrator to deploy and operate the Wi-Fi network.

IV. ECONOMIC AND PUBLIC POLICY IMPLICATIONS

To sum up, the options analyzed present a wide range of economic estimates to serve a community of 19,000 users (K-12 students in the districts supplying data for our model). Their comparability assumes that commercial wireless service is of good quality. Furthermore, it is important to recognize that each estimate can vary substantially. For example, even before considering discounts and other social offers (such as the One Million alternative), purchasing service from a commercial service provider can represent an annual OPEX ranging between $10,260,000 (at a service level comparable to the public-private partnership and self-provisioning options) and $6,840,000 (at lower service quality levels). That being said, the lowest price point of the commercial offer still remains considerably higher than any other options (see Table IV-1).

Table IV-1. Economic comparison of off-campus wireless broadband provisioning options to serve 19,000 students

	CAPEX	OPEX (ANNUAL)	NPV (OVER 5 YEARS)	COMMENTS
3. Purchase public LTE service from a commercial service provider	$ 4,465,000	$ 10,260,000 - $ 6,840,000	$ (46,770,000) - $ (32,688,00)	• Average monthly subscription plan: $45 - $30 • Financials are calculated at full price, without considering any potential discounts and /or social responsibility offers
4. Contract a CBRS based WISP	$ 871,175	$ 248,000 - $ 227,000	$ (4,334,756)	• Reimbursement from WISP to anchor institution increases over time with commercial service penetration
3. Leverage CBRS spectrum to deploy an LTE private network (insource O&M)	$ 3,027,086	$ 206,327	$ (4,728,587)	• Financials exclude other "soft" costs of self-provisioning such as insurance, staff training, administrative overhead, and any regulatory/legal costs to
7. Leverage CBRS spectrum to deploy an LTE private network (outsource O&M)	$ 3,027,086	$ 412,300	$ (6,429,468)	
8. Contract with a third-party integrator to deploy and operate the Wi-Fi network	$ 899,824	$ 742,000	$ (7,015,000)	
9. Hybrid (Private LTE insource + Wi-Fi)	$ 2,215,000	$ 577,000	$ (6,974,000)	• Assumes 50/50 service split between both networks

NOTE: All NPVs are negative because, since there is no revenue charged for service, cashflows are always negative. In the only case where revenues are collected it is from reimbursement from leveraging network to offer commercial services in public-private partnership case.

Source: Telecom Advisory Services analysis

If commercial service provisioning (option 1) is not viable because of low signal quality considerations, the anchor institution faces one of the other four options (note: the hybrid option is a slight modification of the "pure option" ones). The conclusions in this regard are clear:

- If the objective is to serve 19,000 users, most of them located in a high-density geography, where APs can be installed in municipality streetlights and traffic signals, contracting with a third-party integrator to deploy and operate a Mesh Wi-Fi network (option 5) presents the lowest CAPEX. However, OPEX can be significantly increased by the cost of supplying commercial data service to students within the coverage area who cannot receive a reliable connection from the network since this is contingent on the pricing of commercial service. That being said, if the number of users uncovered by the anchor institution network is a small share of the targeted student households (e.g., 1,000 out of 19,000 is assumed in this model), the OPEX declines significantly. In other words, a highly dense user community and a willingness by the municipality or local utility to provide free or subsidized access to vertical assets and backhaul can be a very appropriate option to consider. Furthermore, considering that Wi-Fi unlicensed spectrum allocation is also including the 6 GHz band in addition to 2.4 GHz and 5 GHz (per the FCC decision), the capacity and throughput power per access point will significantly enhanced, which might result in improved deployment economics.[13]
- While CAPEX of private CBRS-enabled LTE networks (option 3) is higher ($3,027,086) than mesh Wi-Fi (option 5) ($899,824), ongoing costs, even if O&M is outsourced (option 4) are quite advantageous for CBRS (because of the cost of supporting users not served by Wi-Fi). Furthermore, the primary benefit of CBRS use is related to opportunity to serve communities with low density that are located in geographies not particularly convenient for large Wi-Fi networks (which require a far greater number of APs).
- Furthermore, the option entailing a public-private partnership that leverages CBRS spectrum (option 2) is more advantageous in terms of CAPEX upfront costs and ongoing OPEX when compared to similar network configuration within a self-provisioned arrangement.
- As a final thought, there are some conditions that are entered in the "drivers" tab that might preclude the implementation of certain options, independently from the economic factor:
    - Commercial operator option: if commercial network coverage is sub-optimal, this option is not viable, or at least not in all areas. Indeed, while this would not be an issue with cable or other fixed service, the unreliability of mobile carrier signals to support remote learning inside homes was frequently cited by school districts surveyed for this project as a motivation for self-provisioning connections (e.g., Lindsay, Fresno and even San Jose).

[13] See Katz, R., Jung, J. and Callorda, F. The economic value of Wi-Fi: a global view (2021-2025). A report for the Wi-Fi Alliance. New York: Telecom Advisory Services. Retrieved from: wi.fi.org; and Katz, R. (2020). Assessing the economic value of unlicensed use in the 5.9 GHz and 6 GHz bands. Washington, DC: Wi-Fi Forward. Retrieved from: wififorward.org/resources.

- Private LTE or public-private partnership leveraging the CBRS spectrum options: if the school district is close to an airport or a defense facility, this will preclude deployment of 60 ft towers in any areas, so this option may not be viable. That said, CBRS does not require 60-foot towers; the lower the antenna,[14] more base stations will be needed. Therefore, this becomes a capex vs. coverage tradeoff.
- Mesh Wi-Fi: this option is most viable where population density is greater (because Wi-Fi has by far the most spectrum and hence data throughput) and where the topography is flat (since 5 GHz and 6 GHz spectrum does not propagate around hills or large buildings as well as lower-frequency LTE spectrum).
- The conditions mentioned above also apply to hybrid configuration (option 6).

[14] Note, though, that most WISPs rely on 5 GHz unlicensed spectrum (point-to-multipoint Wi-Fi in essence) in rural areas; they use high siting (water towers, etc.) to obviate this propagation challenge, but it works and yields far more data capacity than CBRS (which at 3.5 GHz does have better propagation quality).

V. CONCLUSION

The economic assessment of the several options for anchor-led wireless broadband deployments conducted for this study has found that deploying new wireless network connections to-and-through anchor institutions can often be the most low-cost and financially sustainable option to connect households in unserved and underserved areas. In light of this, we recommend that state and federal policy makers allow anchor institutions the opportunity to develop wireless networks, either in conjunction with the private sector or on their own.

VI. ACKNOWLEDGEMENTS

We would like to thank Randy Phelps, Al Brown, Philip Neufeld, JJ McGrath, Andrew Moore, Pete Sonksen, and Michael Houston for contributing their time and expertise to this report. We also thank the following organizations for supporting this project: Infinity Communications & Consulting, Inc.; Kajeet; MORENet; TekWav; Trilogy 5G; and Utah Education and Telehealth Network.

APPENDIX A. TOOLKIT STRUCTURE AND USE

A.1. TOOLKIT STRUCTURE

The toolkit is structured and formatted in such a way that it can be used by schools and other institutions to evaluate the most economic advantageous option for deployment. Along these lines, the models are calculated based on an input function (key drivers) that allows institutions to enter the conditions under which they are considering deployment. That would determine the economics of potential model options, with results displayed in a comparative fashion.

From a structure perspective, the toolkit is programmed in Excel. It is composed of several "tabs":

- **Index:** This is an introduction to the toolkit, although it also contains a series of windows that, when clicked, take you to a specific tab for consultation.
- **Drivers:** This is tab containing key common drivers that condition the configuration and economics of all models. For example, if one inputs that the network should handle 19,000 users, that value will be picked up by all models and will calculate network and corresponding economics of providing connectivity to the same number of users.
- **Calculation tabs**: The next five tabs present some drivers that are specific to each configuration. For example, in the "calculation commercial operator," the user should enter the price of a monthly data plan that needs to be acquired to serve each user. Since this value does not affect other models, it must be inputted only in the "calculation commercial operator" tab.
- **Output tabs:** The next five tabs provide the automatic calculation of economics of each model. The user does not have to input any data at this point.
- **Output comparison:** This tab displays a comparison of the economics of all models.

A.2. TOOLKIT USE

The use of the toolkit involves four steps, of which, as explained above, only the first two require entering data on drivers.

First Step: Entering Data In The Drivers Tab

The key drivers are the common set of variables that condition the configuration and economics of each model. Given that all options need to be compared in terms of their economic profile, these drivers are used to estimate the costs of all models. They are grouped in three categories, as detailed below (see Table III-1).

Table III-1. Economic model driver description

	DRIVER	EXPLANATION/RATIONALE
DEPLOYMENT CONDITIONS	Is the network going to serve students only or a community?	If facility is going to support students only, less network capacity and backhaul is required
	What are the service quality level of commercial carriers (real download/upload throughput, latency)?	If service quality of commercial service is low (e.g., coverage or signal strength indoors), it excludes the option of purchasing service from a commercial carrier
	Is the envisioned network near airports or defense facilities?	If envisioned network is close to one of these facilities, it might preclude building conventional cell towers
	Does the anchor institution have access to EBS spectrum?	If licenses to use EBS spectrum have been leased out to a cellular carrier, they cannot access it for self-provision; it conditions the technology choice
	Does the projected network have access to city poles (such as streetlights, traffic lights)?	City poles provide a good infrastructure for installing high density Wi-Fi network
	If yes, is access for free or at a certain rate charged by the municipality?	Cost of city poles has an impact on a Wi-Fi network economics
	Can schools serve as towers for vertical access?	Schools-as-towers allow for free vertical asset use; do not need county approval
	Does the projected network have access to any other type of municipal vertical assets?	Light poles, water towers, municipal buildings, cell towers
	Is that access to vertical assets subsidized?	If no access to vertical assets exists, towers (typically monopoles) must be erected or leased from a tower company
	Is backhaul for the projected network supplied by school district?	As school districts purchased backhaul, their contribution to the project reduces ongoing network operating costs
	Is backhaul for the network provided by municipality?	If municipality provides backhaul capacity, their contribution to the project reduces ongoing costs
	If yes, is cost allocated based on E-Rate use?	The method for cost allocation has an impact on backhaul costs
	Are there any issues/concerns regarding an antenna outside the customer premise?	Safety of installer, liabilities, insurance requirement might increase self-deployment cost
NETWORK REQUIREMENTS	Network coverage area (sq. miles)	The deployment of users within the required coverage area provides a perspective on the advantage of potential technology options
	Topography	Hilly topography requires the deployment of cellular technology
	Vegetation	Foliage conditions signal propagation and limits the use of certain spectrum bands
	Structures	If community resides in multi-dwelling buildings, it has an impact on CPE
	Number of schools in district	The number of schools has an impact on network deployment
	Average building height	Building (e.g., schools) height impacts the opportunity of using it as vertical assets
	Student population	Conditions network capacity and CPE requirements
	Percent students targeted by the network	This value might drive the need to combine core technology with a complementary one for the non-targeted population (e.g., wireless modem)
	Percent disadvantaged	
	Number of students that have internet access at home	Socio-economic variables
	Number of schools connected	
	Estimated usage per device	Conditions network capacity
	Number of devices to be distributed to users	Conditions network capacity

Table III-1. Economic model driver description, cont.

SERVICE LEVEL REQUIREMENTS

DRIVER	EXPLANATION/RATIONALE
Number of simultaneous users per school	Conditions network capacity
Number of devices running on the network	Conditions network capacity
Share of users in high density zone	Conditions network technology and combination of hybrid (private LTE and Wi-Fi) technologies
Share of users in low density zone	Conditions technology choice
Number of concurrent users	Conditions network capacity
Are users evenly distributed across coverage area	Conditions technology choice (population clustering will allow for mesh Wi-Fi technology)
Service level targets (speed: Mbps down/up)	Conditions network capacity
Service level targets (throttle conditions)	Throttling is a measure to control capacity

Source: Telecom Advisory Services analysis

All data to be inputted by the user in this tab is marked in red in column C. If the cell is not in red, there is no need to enter data. Data to be entered is of two types: numeric and text. In most cases, an explanation is included in column E to help the user find the right answer. If data is of a text type, the user needs to select an answer from a drop-down menu. Once all data in this tab is entered, the user needs to enter model specific data in each of the four calculation tabs (next step).

Second Step: Entering Data In The Calculations Tab

As of now, each of the four Calculations tabs is based on technology specific drivers from real life cases, although the anchor institution using the model might chose to adapt the specific values or assumptions. If this is the case, data can only be entered in red cells of column C.

Calculation commercial operator: User needs to enter two data points: (i) unit cost of a data modem; (ii) monthly cost of chosen data plan. The data in these two fields has been chosen from a likely service to be chosen. However, better offers might exist, or potential discounts could be negotiated.

Calculation private LTE+CBRS: Data to be entered in this tab is more complex. Again, the user needs to fill out red cells in columns C or D. The data included at this time corresponds to the Fresno USD, Connect2Learn (Fresno, Cali.), but some values might change for normalization purposes.

Calculation Wi-Fi: The user needs to fill out red cells in columns C. The data in this case corresponds to the East Side Union High School District (San Jose, Cali.), but some values might change as well. A key value in this case refers to those users that are not covered by the Wi-Fi network footprint and need to receive a data modem and a price plan for a commercial service provider (cell C23).

The costs of a commercial offering are high so this number can significantly alter the economics of this configuration. As mentioned above, better offers might exist, or potential discounts could be negotiated.

Calculation WISP+CBRS: data in this cell is based on the real-life experience of "ConnectME" BVSD (Boulder, Colo.), although some values might have to be changed.

Third Step: Interpreting The Configuration Economic Estimates

As mentioned above, the output tabs are all generated automatically. The cost of chromebooks is excluded from all output tabs because this is a value that should be equally counted in all configurations. However, when estimating total CAPEX this should be added to the economic estimates.

Output commercial operator: the CAPEX number in year 1 reflects the acquisition of data modems paid upfront, while the OPEX reflects the calculation of annual data plan costs for users served.

Output Private LTE+CBRS: The CAPEX estimate (cell C41) includes the network construction costs and the acquisition of CPE. The OPEX estimate has two options because the institution might choose either insource or outsource operations and maintenance. The outsourcing costs are based on Nokia price sheets for the Fresno USD Phase II project, and depend on the number of sites. We believe that pricing an outsourcing option is relevant for project evaluation purposes.

Output WISP+CBRS: The CAPEX estimate (cell C30) includes the network construction costs and the acquisition of CPE. The OPEX does not estimate an insource option as in the model above since a public-private partnership presumes that the WISP is in charge of operations and maintenance. The outsourcing costs are based on Nokia price sheets for the Fresno USD Phase II project. In addition, this model includes a revenue reimbursement, representing a flow of funds from the private partner (the WISP) to the anchor institution for the use of the network for commercial purposes.

Output Wi-Fi: The results in this case correspond to the first phase in the East Side Union School District, but some values might change. A key value in this case refers to those users that are not covered by the Wi-Fi network footprint, which is included in cell C5 for CAPEX and E22 for OPEX. Note the assumption that, as is the case in the San Jose and Council Bluffs cases, CPE is not needed for mesh Wi-Fi, as student devices connect directly to network APs.

Output hybrid: This is a configuration that mixes the private LTE option and the mesh Wi-Fi. The key drivers of this option are cells C39 and C40 in the driver tab (share of users in high density zone and share of users in low density zone). This percent drives the prorated calculation of the two configurations calculated before. In other words, if 50 percent of users are in a low-density area, it considers only half of users to be served by LTE relying on CBRS spectrum and the remainder by mesh Wi-Fi.

Fourth step: output comparison

The last tab in the toolkit presents the results of all calculations for the four configurations discussed above plus some special cases:

- A hybrid option that estimates the cost of serving a community with a mix of CBRS and Wi-Fi technology (this is driven by share of users distributed in high- and low-density zones in cells C39 and C40 in “Drivers” tab.
- An option of insourcing versus outsourcing operations and maintenance.

All results in this tab allow estimating what the most advantageous option from an economic standpoint is along the following dimensions:

- Option that entails the lowest upfront CAPEX outlays.
- Option that represents the lowest annual operations and maintenance expenditures.
- Option that conveys the less negative NPV (although again this does not include any potential revenues to be collected from the service).

Once a first-round comparison of options is made, the toolkit user can go back and fine tune any network specific drivers in the calculation tabs (remember that a change in the upfront “Drivers” tab affects all options equally).

As a final comment, some conditions that are entered in the “Drivers” tab that might preclude the implementation of certain options; these are highlighted in red in column C of each option in the “Output comparison” tab. For example, if the commercial network quality is sub-optimal, this option is not viable as indicated in the cell C6 (even if the economics are calculated in the output comparison tab). However, if conditions are changed in the “Drivers” tab, the non-available options become available.

ATTACHMENT B

Student Home Connectivity Study

See Attached Study

Student Home Connectivity Study

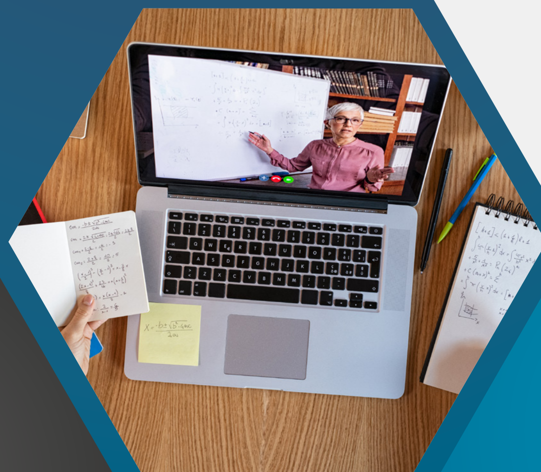
Preliminary findings and recommendations based on the study conducted by CoSN. Made possible by the Chan Zuckerberg Initiative.

CoSN
LEADING EDUCATION INNOVATION

Spring 2021

Remote learning has increased our reliance on the internet

But many school districts lack insight and guidance into how to best ensure a good student experience in online learning. The purpose of the Home Internet Connectivity Study is to provide bandwidth, device, and other guidelines for remote learning.



CoSN gratefully acknowledges the support of the Chan Zuckerberg Initiative.

We also appreciate our data partner, Innive K12 360°.

Table of Contents

Note: This report references commonly-used terms and concepts related to student internet network connectivity. Go to **Appendix A: Glossary** to familiarize yourself with the definitions utilized in the study.

A Letter from CoSN

The Consortium for School Networking (CoSN), is proud to release this important breakthrough study on Student Home Connectivity. Few topics are more timely and critical today than addressing digital equity and closing the so-called Homework Gap.

Digital equity is not a new topic for CoSN. Since our founding, we have focused on addressing the digital divide and ensuring that fast connectivity, devices and equitable use happen in all classrooms. But since March 2020, the imperative of this outside-of-school challenge has become readily apparent to all. The Homework Gap was a chasm for millions of students and educators as the shift to remote learning occurred.

Unfortunately, educators and policymakers have mostly lacked data about the student experience of learning from home. Fortunately, with the help of the Chan Zuckerberg Initiative (CZI), we have data that informs these key findings and recommendations around student home connectivity. The thirteen school districts participating in this exciting project have actionable data for approximately 750,000 students learning from home. Because of this dataset, CoSN is able to provide evidence-based advice to all districts and inform policymakers.

CoSN is eternally grateful to the impressive team at Innive, our data analytics partner, including Gautham Sampath, John Parker, Shahyrar Khazei, Munmun Saha, and Jenny Boronyak. They have gone above and beyond what we hoped when we developed the original concept. Thanks also to our external research partners, Dr. David Drew, Ph.D., and Dr. Frances Gipson, Ph.D., Claremont Graduate University (CA). We would be remiss if we didn't also thank Dr. Tom Ryan, Ph.D., Chief Information & Strategy Officer at Santa Fe Public Schools (NM), CoSN Board Member, and Chair of the Educator Advisory Committee, as well as all the leaders from school districts who are helping us make sense of this initial data. We also thank Ookla for Good for their generosity in providing speed tests to the participating districts. Finally, this work could not be done without the support of CoSN's talented staff.

CoSN sees this study as a key foundational step toward addressing digital equity for students learning from home. There is much work remaining, but the work has begun.

Sincerely,

Keith R. Krueger

CEO, CoSN

Steve Langford

Chair, CoSN Board of Directors

CIO, Beaverton School District (OR)

Introduction

Many families with school-age children have faced significant challenges during the COVID-19 pandemic, an event which has caused an unprecedented shift to online learning. The burden is greatest for the estimated 15 to 17 million students who cannot afford or access a home internet connection. While remote learning is not new in K12 education, it has become a primary learning setting due to the pandemic because it filled a need, allowing students to continue education while school buildings are closed. Many schools are operating remotely in full or part-time mode during and subsequent to the pandemic; however, the lack of adequate internet precludes the child's ability to participate in online instruction or, in some cases, do any schoolwork at all.

Recognizing this imperative, policymakers passed the American Rescue Plan Act in February 2021, which established a new Federal Communications Commission (FCC) program (Emergency Connectivity Fund) with $7.171 billion made available to address internet connectivity needs for students learning from home. In addition, many school districts are using resources provided under the Elementary & Secondary School Emergency Relief Fund (ESSER Fund) to solve remote learning challenges around devices and connectivity.

The need for online remote access for K12 instruction and learning resources is now integral to the US education system. This is a result of several factors.

First, many school districts are offering virtual learning options within existing schools, like remote learning days, or full virtual academies. These options provide varied content and flexibility for schools, students, and teachers to avoid the loss of instructional days during inclement weather conditions and emergencies.

Second, to address the loss of instructional time and engagement caused by the pandemic, many students will need some form of intervention, acceleration, and support. This will be provided in several forms such as tutoring, an extended school year, and online learning resources, which will require student access to devices and high-speed internet.

Third, some students have thrived in the remote learning environment. Many have accelerated academically, more so than they did in the traditional classroom environment. In addition, many parents prefer the option of a more flexible school day which is offered by distance learning. These families may decide to continue their child's education using online methods.

Lastly, even with students returning to the classroom full-time, they still need reliable home internet to participate in class assignments. Ensuring adequate home internet availability provides an opportunity for an equitable education experience.

Regardless of an individual student's chosen learning path, digital tools that were necessary during the pandemic will continue to be leveraged by educators, requiring students utilize home internet access for assignment completion and class participation. School districts require a variety of technologies and strategies to facilitate and expand remote learning access for students, especially for meeting the needs of isolated rural households and other higher cost areas.

About the Home Internet Connectivity Study

With funds provided by the Chan Zuckerberg Initiative (CZI), CoSN has undertaken this study to address home bandwidth, device, and related guidelines for students learning in a remote or hybrid environment. The study was supported and informed by an advisory group of school district technology leaders.

This first-of-its-kind study employed recent de-identified student data to capture the experience of students using computing devices and accessing the internet at home. Each participating school district provided data such as student characteristics, network logs, Quality of Service (QoS) data for meeting software, Internet Service Provider (ISP) data, and geolocation data. Thirteen urban, suburban, and rural school districts representing approximately 750,000 students from across the United States participated in the study over the course of six weeks. The preliminary findings and recommendations in this report have already informed policymakers at the FCC around expanding use of E-Rate funds to address the Homework Gap. This report is also the beginning to ensuring educational technology leaders have data-informed recommendations around student home connectivity.

Note: This study focused on the experiences of students at home and did not include data regarding school or teacher connectivity. Further analysis is required regarding teacher connectivity at school and home. Anecdotal evidence suggests poor connectivity for the teacher can have a significant negative impact on the experience for all students in the class.

Participating School Districts

1. Aldine ISD, TX
2. Beaverton School District, OR
3. Boston Public Schools, MA
4. Ector County ISD, TX
5. Dallas Independent School District, TX
6. Fauquier County Public Schools, VA
7. Forest Ridge School District 142, IL
8. Hillsborough County Public Schools, FL
9. MSD of Wayne Township, IN
10. Santa Fe Public Schools, NM
11. St. Charles CUSD 303, IL
12. Rock Hill Schools York 3, SC
13. Wake County Public School System, NC

Findings Summary

The findings and recommendations in this report are divided into four distinct topics. The recommendations in this report should be considered a guide for school leaders to support local decisions. There is no one-size-fits-all approach to implementing supports for student home internet connectivity. In fact, it is evident that no one solution will meet the needs of all students. Therefore, school districts must use a variety of strategies and interventions to ensure digital equity. The findings in this report are organized into four topics:

1. Learning with Video is Essential for Education
2. Students are Mobile and Rely on WiFi
3. Certain Communities, Especially Remote and Rural Areas, Require More Support and Resources
4. The Remote Learning Experience is Significantly Impacted by Device Quality

1. Learning with Video is Essential for Education

a. Over 85% of network traffic in remote learning is used for video (both synchronous and asynchronous).

b. A sufficient upload speed is critical for uninterrupted participation in synchronous video.

c. A sufficient download speed is critical for uninterrupted viewing of synchronous or asynchronous video.

d. Video-intensive content and applications are increasing in use and this trend is expected to continue for the foreseeable future.

2. Students are Mobile and Rely on WiFi

a. Many students participate in online learning activities outside of the student's home, including joining from peers' homes, and even attending classes from other cities, states, and countries.

b. 92% of students use WiFi instead of a wired connection, which makes it critical to address home WiFi issues.

c. Alongside district-provided devices, students often concurrently use mobile devices, such as their personal phone or tablet, which contributes to increased home bandwidth needs.

3. Certain Communities, Especially in Remote and Rural Areas, Require More Support and Resources

a. Students in more remote or rural areas most often have limited internet access.

b. Students working in areas with a large concentration of students may experience poor connectivity.

c. Even students from higher socioeconomic families have frequent problems in remote learning/online meeting experiences.

4. The Remote Learning Experience is Significantly Impacted by Device Quality

a. Quality of student experience can be impacted by age, type, and quality of device, as well as device configuration (i.e., user authentication and network filtering tools).

b. Student experience can be improved by routinely collecting datasets that provide insight into the student use of district-provided devices.

In addition to the findings and recommendations in this report, the study helped to determine recommendations for student home internet bandwidth requirements.

Student Home Bandwidth Recommendations

Students need fast internet connections to participate in remote learning. The current FCC household minimum bandwidth guideline of 25 Mbps download speed and 3 Mbps upload speed is inadequate to support even a single student in a household, let alone multiple students. Based on the findings in the study, CoSN recommends a per-student minimum bandwidth standard of a download speed of 25 Mbps and upload speed of 12 Mbps to support concurrent activity and usage.

To determine this recommendation, actual network traffic was reviewed to identify applications used, how much traffic is going to each application, and how much of the traffic is video. Analysts in the study identified the activities where bandwidth is needed based on actual network traffic patterns. Then, they researched the recommended bandwidth from application vendors to determine the estimated bandwidth for the activity. Network traffic was also used to analyze activity concurrency; that is, students regularly perform more than one activity at a time. For example, one student may be actively participating in an online meeting while simultaneously performing an internet search via web browser while, in the background, email is automatically refreshing. This scenario, and others like it, are extremely common in remote learning. For this reason, it is important that a minimum is set at 25 Mbps download and 12 Mbps upload speed.

In addition, it's crucial to highlight the importance of a per-student standard and not a per-household standard like the current FCC recommendation. Standards should be set at the student level and account for the total number of students in the home. For example, network requirements to support a home with six children should be different from network requirements to support a home with one child.

These recommendations are based on the current environment needs. In light of constantly evolving technologies, minimum bandwidth recommendations should be revisited regularly, at least every three years. Support for higher video resolution, such as 1080p high definition (HD) and 4K, will most likely be required in the future. In addition, many new technologies, such as eSports, Augmented Reality (AR), and Virtual Reality (VR) will likely be used to deliver instruction. These kinds of advanced technologies will require at least 25 Mbps download/upload speed for standard definition (SD) and up to 500 Mbps download/upload speed for 4K video.

Student Home Bandwidth Calculator

CoSN Institutional Members will receive exclusive access to the Student Home Bandwidth Calculator, which is a tool for determining the recommended amount of available bandwidth for students based on concurrent activity and usage. The calculator provides the estimated bandwidth for each activity and automatically adds up the required bandwidth for a set of students performing selected activities.

Student Activities During Online Instruction and Estimated Bandwidth

Student Bandwidth Usage	Resolution	Download (Mbps)	Upload (Mbps)
Email -- Is used to communicate to students by teachers, administrators, and other students.	n/a	1	1
Web Browsing -- Students access the internet frequently to research topics using a web browser and search engine such as Google or to read blog articles. Ad services related to various websites also consume a significant amount of bandwidth.	n/a	1	0.5
Learning Management System -- Students use a learning management system such as Canvas, Google Classroom, Schoology, PowerSchool, or D2L to access and submit assignments and communicate with their teacher and other students.	n/a	1	1
Video Instructional Content -- Students access video instructional content from sources such as PBS Kids, Khan Academy, Newsela, McGraw Hill, Discovery, National Geographic, YouTube, etc.	SD	3	0.5
Online Assessments -- Assessments for essential skills and content knowledge are provided online and taken at home. Assessment software can be divided into two broad categories: formative and benchmark. Examples of formative assessment software include Edpuzzle and Edulastic. Examples of benchmark assessment software include iReady and Renaissance.	n/a	1.5	0.5
Cloud Storage -- Students download and upload homework assignments using cloud storage such as Google Drive or Office 365.	n/a	5	2
Online Meetings -- Students participate in daily online meetings with teachers using an online video tool such as Google Meet, Zoom, Cisco Webex, or Microsoft Teams. In addition, online meetings are used for counseling and providing services for English Learners and students with disabilities. Students frequently participate in small group instruction sessions and use video to communicate with teachers and other students.	SD	3.2	3.2
Feedback -- Asynchronous video is frequently used by teachers and students to communicate and provide feedback to each other. Teachers and students often record videos using software from companies such as Loom and Screencastify to communicate. Other feedback tools are provided by companies such Class Dojo and Edmodo.	SD	2	2
Instructional Support -- Interventions and instructional support are provided through online resources. Many companies such as Edgenuity, Renaissance and Illuminate provide solutions in this category.	n/a	3	1
Multiple Devices -- Students frequently use two or more devices to access the internet (e.g. Computer, Tablet, Smart phone, etc.)	n/a	1	1
Educational Gaming Technology -- Instruction is often provided through software such as Kahoots, BrainNook, FunSchool, Socrates, ZooWhiz that utilize gaming technologies.	HD	5	1

CoSN is vendor-neutral and does not endorse products or services. Any mention of a specific solution or company is only for contextual purposes.

Detailed Findings & Recommendations

1. Learning with Video is Essential for Education

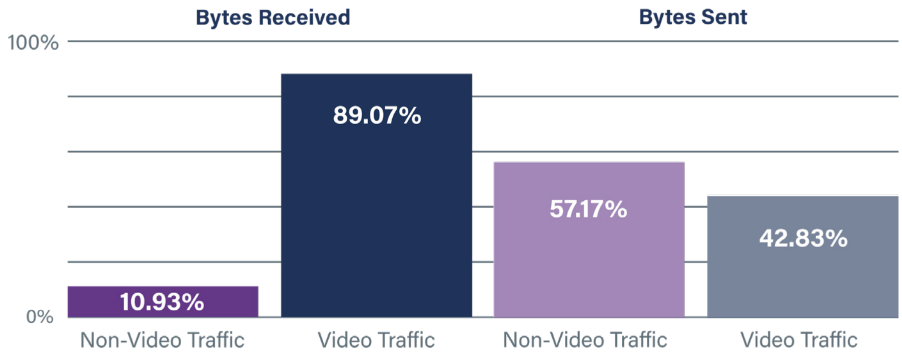
Video (both synchronous and asynchronous) is used extensively in remote learning environments to deliver instruction and to communicate with students in online meetings. Network logs from thirteen (mostly large) districts revealed that over 85% of the network traffic to support students in a remote learning environment is used for video, both for direct instruction and instructional supports. These applications use a significant amount of data and are often run concurrently with the synchronous video classroom sessions.

Synchronous video sessions, like in online meeting tools, provide an effective method for students to feel more connected by virtually interacting with their teacher and other students. However, the extensive use of video by students requires adequate upload bandwidth. Video is a growing trend in K12 education, and it is used for much more than just providing lectures or viewing learning resources. For example, students use video to interact with each other in small group instruction; teachers often encourage or require students to leave cameras on to monitor and support student engagement and participation; and students often use video to submit homework assignments and communicate with their teachers.

Over 70% of students live in a household with one or more other students.

According to the study, over 70% of students live in a household with one or more other students. Concurrently supporting multiple students using video from the same internet connection is problematic when bandwidth availability is low. Home network bandwidth capacity must account for concurrent usage by multiple students, including current video use.

Most broadband connections offer different speeds for downloading versus uploading. In the past, uploading data was not as common a task as it is today; therefore, the Federal Communications Commission (FCC) established a household minimum standard of 25 Mbps for download speed and 3 Mbps for upload speed. However, 3 Mbps is not an adequate upload speed to support distance learning for an individual student, let alone multiple students in a household.



The above graph depicts video versus non-video network traffic for all participating school districts. Traffic sources that were analyzed to determine video use include web-based applications such as online meeting tools, video streaming, learning management systems, and other learning tools.

Recommendations for Learning with Video

Increase the Minimum Standard for Student Home Internet Bandwidth - School districts must assure home internet access provides sufficient enhanced upload availability. As previously mentioned, the current FCC household broadband definition of 25 Mbps download speed and 3 Mbps upload speed is inadequate and should be replaced by a per student broadband definition. A new minimum standard should be set at 25 Mbps for download speeds and 12 Mbps for upload speeds per student.

When calculating the bandwidth requirements for a household, the recommended per student bandwidth requirements should be multiplied by the number of students in the household and adjusted for other household members and factors impacting internet usage.

Remove Data Caps for Classwork and Learning Activities - Given the new requirements of video conferencing for classroom communication and student collaboration, ISPs receiving federal support should provide unlimited data for home learning connections without throttling.

2. Students are Mobile and Rely on Wi-Fi

During the study, many students participated in online school activities from locations outside of the student's home. Students accessed school learning resources from other student homes and even other cities, states, and countries. In the study, many students shared an IP address with other students that were not from the same household. Likely causes include students wanting social interaction with other kids, finding a faster internet connection at a friend's house, and parents who share childcare responsibilities.

In addition to other student homes, the study also identified a trend in students accessing the internet from more than two locations during the six-week period of the study. For example, a student living in Santa Fe, New Mexico, may also participate in learning from Albuquerque, New Mexico; Dallas, Texas; and Mexico.

Online meeting software data revealed that, regardless of the student's IP address, 92% of students in the study connected to the internet via WiFi instead of a wired connection. However, WiFi presents significant challenges. Factors such as router location, home construction, and available support for modern router standards can impact the strength of the WiFi connection.

92% **of students connect to the internet via WiFi instead of a wired connection.**

For example, mounting a router on a brick wall or placing it behind a television can impede WiFi signals. Just as important is to consider the home construction materials, such as plaster or concrete, which can also weaken a WiFi connection. When needed, families of students should receive guidance from the school district regarding appropriate WiFi router placement to mitigate obstacles in student internet access.

Many users believe they have slow internet connection, but in some cases the real problem is slow WiFi that is delivered through older routers using outdated wireless standards. A new WiFi standard (802.11ax) has just been released which should provide a much stronger WiFi connection.

Students are not just using WiFi on their district-provided devices to participate in online learning activities. According to device usage data captured in the study, many students concurrently use their personal phone or tablet in addition to their district-assigned device to participate in online meetings. Using multiple devices simultaneously will contribute to increased home bandwidth requirements.

Recommendations for Home WiFi

School districts must ensure that students not only have high-speed bandwidth to the home, but that the student receives dedicated high-speed access within the home. Student households must have a sufficient router to support the number of users and devices in the home. Here are some steps to be taken by school districts:

- Help families acquire new routers if their router has not been upgraded in a few years
- Work with ISPs to replace outdated routers
- Provide network extenders in areas with poor signals
- Educate families on router placement and maintenance

Since so many students use WiFi from various locations, school districts should enforce authentication of students in order to access district resources. This ensures only known students are connecting from outside the district, state, and country to learn. It also provides the ability to identify users, provide better support, and provide a safe and secure learning environment.

Security

It's important to be vigilant about student and district data security. Public and private institutions like school districts are common targets for hackers. Having fine-tuned filtering and authentication tools in use helps address security vulnerabilities before attacks can occur.

3.
Certain Communities, Especially Remote and Rural Areas, Require More Support and Resources

Through review of ISP data (Form 477 data obtained from the FCC) and Ookla Speed Test® data, the study identified upload and download speeds within small geographic areas in each school district. Generally, the study found that the majority of cities and suburban areas where students live have high speed internet available (Source: FCC Form 477) and deployed in the home (Source: Ookla Speed Test®). However, students in more rural areas or on the edges of suburban areas can have extremely limited internet availability and access.

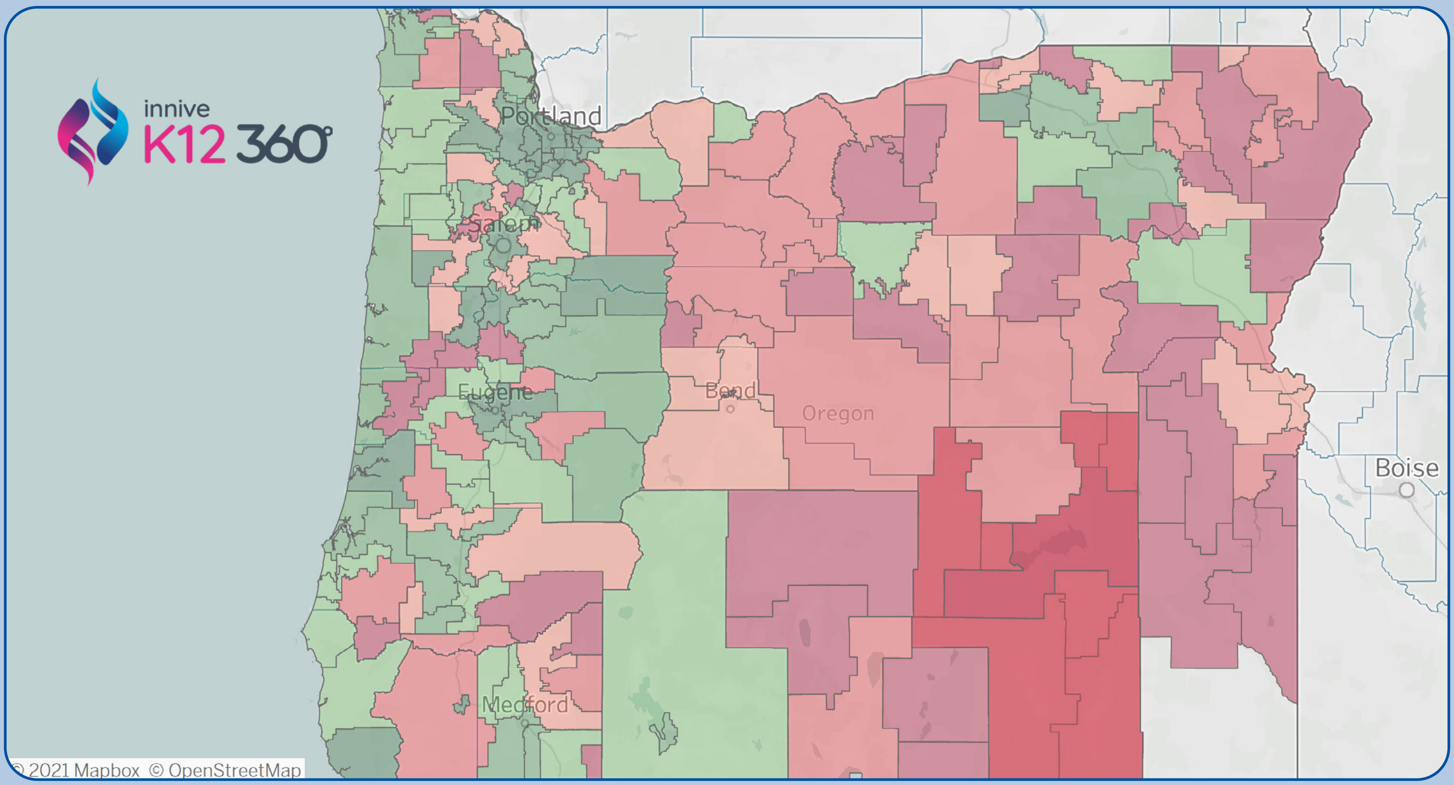
Likewise, users within high population areas of a city also experience limited internet speeds. For example, Santa Fe Public Schools found that areas with large concentrations of students, like in mobile home parks or subsidized apartment buildings, frequently have poor levels of throughput. This inequity may be attributed to capacity issues on the part of ISPs brought about by oversubscribing or related to overloaded network switching equipment.

While remote and rural areas are a primary concern, the study also found that students living in areas with above average socioeconomic status (SES) do not automatically have access to adequate home internet. The study examined network resources used for online meetings and organized them by student and IP address. Students using IP addresses in areas with higher SES and available access to excellent internet connectivity still see frequent problems with their online meeting experience in the home.

The cause for poor meeting experiences may vary from suboptimal network equipment in the home to multiple devices (e.g., smart devices, Internet of Things, etc.) accessing the network concurrently. Multiple devices and people sharing the same network resources significantly reduces resources available to students for learning. Students and families may require education and technical support around best practices to improve their online meeting experiences.

To quickly address internet access needs produced by the pandemic, some ISPs have begun offering free satellite internet for a limited time and government-funded discount programs like Lifeline and the new Emergency Broadband Benefit program to qualifying families and households. When funds are available, school districts may offer the option of portable hotspots to students. However, these solutions often come with data caps that limit the amount of online work a student can perform.

Illustration of Oregon Bandwidth by School District



This map, created by Innive K12 360°, shows an example of the difference in available bandwidth (according to Ookla Speed Test® data) between rural/remote school districts and urban school districts [according to their territory classification by the [National Center for Education Statistics (NCES)](#)]. In Oregon, one can clearly see that the more remote school districts in the southeast corner of the state have poorer connectivity than urban and suburban school districts along the west coast.

Recommendations for Supporting Communities in Need:

Below are specific recommendations for this area. As previously mentioned, it's important to note that there is no one-size-fits-all approach to connectivity solutions. Each solution has its strengths and weaknesses depending on the diverse challenges and needs of the students, school district, and community.

- **Flexibly provide students with hotspots for areas with limited internet access using requested E-Rate funds.** It is critical that adequate internet bandwidth is available to all students including students who do not have permanent homes; students that may frequently move; or students that rely on emergency locations for shelter and care. The National Center for Education Statistics reported that for school year 2015-16, 2.6% of public elementary and secondary students were homeless[1]. For this reason, location flexibility is important when determining strategies for providing students with hotspots or other access points.
- **Work with ISPs and community leaders to ensure that ISPs offer suitable plans for the community.** This includes adequate bandwidth availability and lower pricing for students and families.
- **Leverage new federal and state funding, such as the Emergency Connectivity Fund that the FCC is establishing, to leverage a variety of internet access pathways.** School districts should choose the solution(s) that works best for its environment:
  - **District-Provided Mobile Wi-Fi (like buses, stadiums, etc.) –** This approach uses mobile WiFi delivery points and works particularly well for providing WiFi access to high density residences such as apartment complexes and mobile home parks. Using this model, the district implements dependable, high-speed WiFi on a school bus or in a public location that can broadcast WiFi capabilities to households in surrounding areas. Optimally, connections are limited to school-owned devices to ensure bandwidth is preserved for school-related activities. Many districts have applied this approach; for example, Kanawha County School District (WV) offers WiFi-enabled school buses that can be strategically placed in certain areas to provide internet service to students who do not have the ability to connect at home. When in-person school is in session, students have the opportunity to use the WiFi available on the school bus to complete schoolwork before and after the school day.
  - **District-Provided Citizens Band Radio Service (CBRS) –** CBRS is a private, two-way communications service that traditionally provides voice services but can also transmit data packages and extend internet connectivity. School districts can use CBRS to stand up private CBRS 4G and 5G networks. Boulder Valley School District (CO), among other districts in the country, have chosen this approach.
  - **Long-Term Evolution (LTE) Broadband –** LTE Broadband is a 4G wireless connection that is similar to district-provided CBRS. It may be carrier-provided or owned and operated by the district. Carrier-provided approaches leverage a provider-owned LTE radio access network (RAN) to connect end user devices in homes via carrier-provided radio transmissions. Dallas ISD (TX) is one of many school districts using this approach.

1 National Center for Education Statistics, Digest of Education Statistics, Table 204.75a. Homeless students enrolled in public elementary and secondary schools, by grade, primary nighttime residence, and selected student characteristics: 2009-10 through 2015-16

- **Satellite –** Offering internet access via satellite connectivity is an increasingly viable option, particularly for access in rural areas where connectivity reliant on transmission via cable, fiber, or cellular service is less likely. Internet access through satellite eliminates the need to build miles of infrastructure to deploy services to remote locations. Satellite internet can also be leveraged to connect those students living in locations where other options are not available. Many districts have implemented this solution, such as Ector County ISD (TX).
- **Cellular Hotspots -** Cellular hotspots are an increasingly common strategy for addressing lack of home connectivity by school districts and libraries. Because hotspots are dependent on the cellular network, they will not work in many parts of the country, including more rural and remote communities. Cellular hotspots should be distributed/allocated per student not per household. Unless the cellular network can meet the recommended bandwidth requirement described on page 5, this should not be considered a long term solution.

To ensure the success of activities and programs, such as providing internet hotspots and other devices, school districts must provide channels for technical support. For example, school districts utilizing online learning resources should provide technical support resources for families to address suboptimal internet access. To accomplish this requires the use of funds to provide enhanced resources such as training content and, if possible, expanding help desk resources and equipping technical support staff with better tools to address home connectivity issues. Here are some areas where additional district-provided technical support is needed:

- Help families identify and troubleshoot slow internet problems in the home
- Educate families on router maintenance and placement
- Provide tools to assess weak WiFi signals
- Work with application service providers to improve application performance

4. The Remote Learning Experience is Significantly Impacted by Device Quality

Computing devices that are designed for work in classroom environments (e.g., strong WiFi signal and no demand for synchronous video), may not be sufficient for remote learning and home environments. High quality devices are important to instruction for many reasons, especially in lower grade levels that are more dependent on synchronous video and secondary grade levels which offer programs like career technical education which may require devices that depend on higher-processor applications.

According to data regarding the types and performance of district-provided devices, upload and download speeds during online classes/meetings can vary significantly by the age, type, and quality of device used. Students that were provided with older and less powerful equipment had an inferior experience than students with newer devices. Students that received newer devices with limited specifications (e.g., memory and processor) also had more challenges than students that were provided with devices with better specifications. To determine this, the study included examining students who were using the same ISPs and their device information to show that some students experienced a significant reduction in throughput depending on the device used. There are several factors that can contribute:

- Type and speed of processor
- Amount of memory
- Central Processing Unit (CPU) utilization
- Number of applications running at one time
- Quality of WiFi antenna and signal strength received
- WiFi standard used and access frequency

In addition to characteristics such as device age, type, and quality, *device configuration* can have an impact on student experience. For example, requiring user authentication for online classroom or meeting participation can provide significant insight into meeting sessions. On the other hand, network filtering products can provide usage data but they can also slow down an internet experience, especially when used on websites for online meeting tools and virtual classrooms. These online applications should be whitelisted in the network filter to improve student experience. Impact on device network throughput should be included as criteria for the evaluation and selection of network filtering products and services.

In working with thirteen districts, the study discovered that most school districts do not routinely collect quality, curated data to assess device and home connectivity issues. To determine its findings and recommendations, this study depended on large volumes of data and APIs which most districts do not have the resources to collect or implement. Data was harvested from network logs and quality of service (QoS) data from online meeting software. The study also involved the extraction and analysis of hundreds of millions of records. This included using APIs to determine access locations and ISPs for each online meeting conducted. Advanced geospatial capabilities were used to determine geographic areas needing attention because of suboptimal internet connections.

School districts need sophisticated information and data systems to adequately manage home connectivity and ensure students are provided ample resources to learn. With access to this type of adequate data analytics, the participating school districts have been able to work with ISPs, application service providers, families, and community resources to address identified obstacles to adequate home internet access. Without actionable data, school districts may make ill-informed judgements, exhausting limited financial resources. In addition, many school districts continue to use basic methods of data collection and analysis, like spreadsheets. Districts that have advanced data and analytics available are better able to make quick, well-informed strategic decisions.

Recommendations for District-Provided Devices:

Students need a high-quality device(s) to participate in online remote learning. Device capabilities must sufficiently support the needs of the student, whether the device is required for basic classroom use like online classwork and non-synchronous video or advanced use like coding and content creation. The following factors, provided by participating districts, should be considered when purchasing learning devices for the home or student use:

- CPU type, speed, and number of cores
- Amount of memory
- WiFi connection
- Integrated webcam
- Integrated microphone
- Headphone port

Device requirements vary by how the student uses the device. Go to the URLs below to view device requirements for applications and devices commonly used in K12 education.

Google Meet
http://bit.ly/GoogleMeetReq

chromebook
http://bit.ly/GoogleDeviceReq

zoom
http://bit.ly/ZoomDeviceReq

Cisco webex
http://bit.ly/WebExDeviceReq

Microsoft Teams
http://bit.ly/TeamsDeviceReq

Note: CoSN is vendor-neutral and does not endorse products or services.

Using funding to improve data capture and analysis will help districts make more informed decisions around student devices and home internet supports. Here are some areas where improved data and analytics capabilities can benefit school districts:

- School districts need the ability to capture internet speed and quality data and integrate it with other datasets. For example, Ector County ISD is incorporating the ability to capture data such as the location, download speed, upload speed, latency and jitter (i.e., time delay in data delivery) every time a student signs into the student learning management system.
- School districts need to work with online video conferencing software to provide aggregated Quality of Service (QoS) data at the student level to assist in identifying students that are experiencing issues during online instruction.
- Internet speed data should be integrated with other student data such as assignments and assessments to determine the impact on student participation. This requires extending the industry-recognized Ed-Fi Data Standard and providing a standard API, which could be used for a variety of purposes. For example, before assigning an intervention to students, the school district should have data available to determine if the student has appropriate internet access to participate in the intervention.

Appendix A: Glossary

Term	Description
Asynchronous Video	The viewing of the video takes place after the video has been created. An adequate download speed is required for viewing videos in different scenarios, such as viewing video in online video platforms, LMS discussions and assignments, and recorded lectures. See synchronous video.
Authentication	For the purpose of this report, computer applications and tools that are used to authenticate, or verify, the identity of an individual who is attempting to log into a district device or online application.
Bandwidth	The maximum amount of data that can travel through an internet network. See throughput.
Cloud Storage	A repository used for storing files in a location that can be accessed using a web browser. Cloud storage makes it easier for people like students, teachers, and parents to share and concurrently access documents and files. Popular cloud storage applications include Microsoft OneDrive, Google Drive, and Dropbox.
Data Cap	A limit on the amount of data an individual can use on a given device. Data caps are usually agreed-to on a per-month basis. After the limit is reached, the individual usually receives extra charges and/or experiences throttling.
Data Packet	A unit of data that travels along an internet network. See jitter.
Device	For the purposes of this report, any type of internet-enabled computer technology used to access digital files, including but not limited to laptops, personal computers (PCs), tablets, and smartphones.
Download Speed	The speed at which an internet network retrieves information.
Filter	For the purposes of this report, an application applied to a district-provided device that enables schools to ensure students do not use the district-provided device to access inappropriate or non-school-related websites and applications.
Hacker	An individual who use computers to gain unauthorized access to information.
Home Setting	Students may participate in remote learning activities outside their official home address, including the homes of friends, relatives, or other family members. For the purpose of this report, "home" can refer to any residence in which the student logs into at least one remote learning activity, unless otherwise specified.
Jitter	A measurement in milliseconds of the variation in latency. High jitter has a negative impact on activities like participating in online meetings and streaming live videos. See Data Packet, Latency.
Latency	A measurement in milliseconds of the time it takes for a data packet to travel from a source to the destination and back. See Data Packet, Jitter.
Meeting (Online Meeting)	For the purposes of this study, an instance in which two or more users connect with one another in real-time synchronous audio and/or video via a web browser. Commonly used online meeting applications include Microsoft Teams, Google Meet, and Zoom.
Mbps	Acronym for "megabits per second" used in reference to download and upload speeds.

Term	Description
Modem	An object that connects a home network to the broader internet. The modem performs different functions than the router but may be provided to ISP customers in one box.
Pod	A group of students (typically 3-7) learning online together in a shared space. Pods are often supervised by adults such as parents/guardians or privately-hired tutors.
Processor (CPU)	A physical hardware component within a computing device that enables the device to interact with installed applications. Most computers consist of multiple processors in addition to the CPU. A higher-capacity processor is necessary for advanced student activities like computer-aided design (CAD) or video editing.
Quality of Service (QoS) Data	For the purposes of this study, QoS data refers to data specifically pulled from online meeting tools like Zoom, Google Meet, or Microsoft Teams that includes information about meeting session performance organized by participant (e.g., missing/dropped participants, jitter, latency, etc.).
Remote Learning	A learning setting in which student completion of learning activities (such as lectures, assignments, assessments, extracurricular activities, and more) takes place outside of the traditional in-person school environment.
Router	An object that allows all connected wired and wireless internet-enabled devices to access the internet by routing information to/from devices. The router performs different functions than the modem.
Synchronous Video	Online meeting platforms like Zoom, Google Meet, and Microsoft Teams that allow students and teachers to converse and collaborate in real time through audio, video, and screen sharing. See asynchronous video.
Throttling	The intentional slowing or limiting of an internet service by an ISP to reactively regulate bandwidth traffic, reduce congestion, and/or avoid overloading device processing capacity.
Throughput	Whereas bandwidth is the amount of data that can possibly travel through an internet network, throughput is how much data actually does travel through a network successfully. This can be limited by a ton of different things including latency, and what protocol you are using.
Upload Speed	The speed at which an internet network sends information.
Web Browser	A computer application used to access web-based applications and webpages. Commonly used browsers include Google Chrome, Mozilla Firefox,and Microsoft Edge. An internet connection is required for use.
WiFi	A technology used for access to the internet that does not require a physical wired connection to the device. Instead, the device receives radio waves carrying data packets.
Whitelist	The ability to provide permissions to an application for automatic access on a network filtering tool or other security application. The process of "whitelisting" allows an application to bypass filters or authentication tools to improve network performance.

Appendix B: Advisory Committee Members

Name	Title	Organization
Andrew Moore, MBA	Chief Information Officer	Boulder Valley School District (CO)
Christine Fox	Senior Director of External Relations	CoSN
Eileen Belastock, CETL	Director of Technology and Information	Nauset Public Schools (MA)
Jeremy Bunkley	Chief Technology Officer	Hillsborough County Public Schools (FL)
Julia Legg	State E-Rate Coordinator	West Virginia Department of Education (DC)
Keith Krueger	Chief Executive Officer	CoSN
Kellie Wilks, Ed.D.	Chief Technology Officer	Ector County ISD (TX)
Louis McDonald	Director, Technology Services	Fauquier County Public Schools (VA)
Mark Finstrom, CETL	Chief Technology Officer	Highline Public Schools (WA)
Mark Racine	Chief Information Officer	Boston Public Schools (MA)
Steve Buettner	Director of Media and Technology	Edina Public Schools (MN)
Tom Ryan, Ph.D.; Advisory Chair	Chief Information and Strategy Officer	Santa Fe Public Schools (NM)

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