May 31, 2023

Submitted via email to ITSinfo@ntia.gov

Hon. Alan Davidson
Assistant Secretary of Commerce for Communications and Information
National Telecommunications and Information Administration
U.S. Department of Commerce
1401 Constitution Ave, NW
Washington, DC 20230

Re: **Comments of the Schools, Health & Libraries Broadband Coalition and the Consortium for School Networking in Response to the Request for Feedback on the Institute for Telecommunication Sciences CBRS Report**

Dear Administrator Davidson:

The Schools, Health & Libraries Broadband Coalition (SHLB)[1] and the Consortium for School Networking (CoSN) provides these comments in response to the National Telecommunications and Information Administration's (NTIA) Institute for Telecommunication Sciences (ITS) report regarding the analysis of data concerning the Citizens Broadband Radio Service (CBRS) band.[2] SHLB and CoSN applaud NTIA's efforts to assess the state and growth of CBRS since the start of its operations and welcomes this opportunity for public feedback on its findings. Access to spectrum has allowed many community anchor institutions (CAIs) to create innovative broadband solutions to bridge the digital divide in their communities. In addition to their typical service offerings for use of schools, libraries, healthcare providers and

---

[1] SHLB is a nonprofit public interest organization with the mission of promoting open, affordable, high-quality broadband for community anchor institutions and their communities. Its membership is comprised of a broad base of organizations including representatives of schools, libraries, health care providers and networks, state broadband offices, private sector companies, state and national research and education networks, and consumer advocates. *See* http://shlb.org/about/coalition-members for a complete list of SHLB coalition members.

[2] Douglas Boulware, Anthony Romaniello, Rebecca L. Dorch & Michael G. Cotton, An Analysis of Aggregate CBRS SAS Data from April 2021 to January 2023, NTIA, U.S. Dept. of Commerce (May 2023), https://its.ntia.gov/umbraco/surface/download/publication?reportNumber=TR-23-567.pdf.

networks, CAIs have increasingly worked with private sector companies or self-deployed wireless networks beyond their four walls to provide low-cost (typically free) broadband service to the surrounding community.[3] SHLB uses the term "anchor-enabled network" to describe how broadband is deployed "to and through" the CAI to reach residential consumers. To set up these networks, many CAIs rely on shared spectrum available through the CBRS band. As NTIA continues to analyze the prospective growth and uses of CBRS, SHLB and CoSN urge leaders to consider the value that CBRS (as well as other shared, licensed, and unlicensed spectrum bands) provides not only to various direct users like CAIs, but to the communities at large that benefit from them.

In August of 2022, SHLB and the Open Technology Institute at New America (OTI) released a study by Dr. Raul Katz demonstrating the economic feasibility of "to and through" networks whereby a CAI extends wireless broadband signals to residences in a surrounding community.[4] His research compared various anchor-enabled network models (with data supplied from K-12 school districts) and analyzed a range of economic estimates of each option over a five-year period to serve a community of 19,000 users. When deploying wireless broadband services to users off-campus, a CAI decides who will provision network services[5] and which technology best fits with the overall structural design it chooses. Such technologies include wireless networks and spectrum bands, such as CBRS spectrum, Educational Broadband Service

---

[3] For example, a school, library, or community organization can place antennas on the roof of its building to transmit wireless signals to surrounding homes and businesses. Some households lack Internet access due to lack of broadband infrastructure to their homes. Others lack broadband service due to the fact they cannot afford the service, or lack a device, or do not understand why Internet service can benefit their lives.

[4] 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.

[5] The CAI could purchase service from a commercial wireless service provider; contract or partner with a non-traditional service provider (like a WISP or network integrator) and structure a public-private partnership whereby the provider is responsible for building and operating the off-campus network; or self-provision its own networks using its own personnel and infrastructure. *Id.* at 10.

(EBS) bands, unlicensed Wi-Fi spectrum, or a combination of these.[6] Dr. Katz's report presents economic considerations, including investment and operating expenses, and results of the technology-based options CAIs may choose to deploy, including whether they: i) purchase LTE service from a commercial wireless service provider; ii) contract with a CBRS-based Wireless Internet Service Provider (WISP); iii) leverage CBRS spectrum to deploy an LTE private network; iv) deploy a mesh Wi-Fi network with unlicensed spectrum; or v) utilize other options like EBS spectrum or TV white spaces. Generally, he found that deploying new wireless connections "to and through" a CAI using strategies found in options ii) through v) "can often be the most low-cost and financially sustainable option to connect households in unserved and underserved areas."[7] Dr. Katz's full economic report is attached as Appendix 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.[8] These studies showcase CAIs implementing "to and through" solutions including those institutions that self-deployed private LTE networks by using shared CBRS spectrum.

- For example, in Harris County, Texas, the Harris County Broadband Office partnered with the Harris County Public Library and nine public school districts to create Project Nitro in December 2020, as a response to the COVID-19 pandemic and the uptick in remote learning. Through this project, Harris County is deploying multiple Motorola CBRS base stations that may be located on county buildings, public infrastructure, or monopoles.[9] When a coverage area is live, the school in that area notifies those student households that they can retrieve their

---

[6] *Id*. at 5. Choice of one technology over another, however, may be constrained by the spectrum available to the CAI. For instance, many EBS licenses have been leased to a commercial ISP and are no longer available to CAIs. *Id*. at 11.

[7] *Id*. at 3.

[8] 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. (OTI Case Studies).

[9] OTI Case Studies at 49.

customer premise equipment (CPE) from the library.[10] As of April 2022, three pilot base stations were in operation, connecting approximately 500 students.[11] Twenty additional stations have also been fully constructed with coverage areas identified and maps provided to school districts so they can notify student households about available CPEs for those areas.[12]

- The Fresno Unified School District (FUSD) in California developed its own private LTE network using CBRS spectrum to provide broadband to unconnected student homes. FUSD previously considered using either Educational Broadband Service (EBS) spectrum and meshed Wi-Fi solutions, but found that Fresno County and Fresno State University had leased applicable EBS licenses in the area to carriers, and that the city wouldn't move forward with a proposal to mount Wi-Fi transmitters on city-owned street light poles.[13] FUSD thus decided to primarily mount access points on school buildings to create its own wide-area solution.[14] Phase one of the project, which has since been completed, spans 24 school neighborhoods, and phase two will fill coverage gaps and expand the network to cover the entire student population.[15]

A full copy of the case studies, which highlight additional CBRS-backed networks, is attached as Appendix B.

Anchor-enabled broadband networks provide unique connectivity solutions that can reach communities lacking access to broadband. They also allow a community the autonomy to build and operate its own broadband system to meet the needs of its local customers, often promoting and stimulating needed competition in the marketplace by establishing an affordable internet service offering. CBRS spectrum additionally provides an important asset that communities can use to promote long-term digital equity goals even if Congress is not able to provide ongoing

---

[10] *Id*.

[11] *Id*. at 50.

[12] *Id*.

[13] *Id*. at 26.

[14] *Id*. at 25.

[15] *Id*.

funding for the Affordable Connectivity Program (ACP). As NTIA evaluates the growth of CBRS, it should recognize CAIs as innovative users of the CBRS spectrum band, foster future development of these networks, and ensure users like CAIs have allowed access to shared, licensed, and unlicensed spectrum.

Respectfully Submitted by,

/s/ Kristen Corra

SCHOOLS, HEALTH & LIBRARIES
BROADBAND (SHLB) COALITION
Kristen Corra
Policy Counsel
1250 Connecticut Ave. NW, Suite 700
Washington, DC 20036

/s/ Keith Krueger

CONSORTIUM FOR SCHOOL
NETWORKING
Keith Krueger
Chief Executive Officer
1325 G St. NW, Suite 420
Washington, DC 20005

APPENDIX 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

TELECOM ADVISORY SERVICES

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.

OPEN TECHNOLOGY INSTITUTE

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**.

SHLB
SCHOOLS, HEALTH & LIBRARIES BROADBAND COALITION

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

CONTENTS

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.

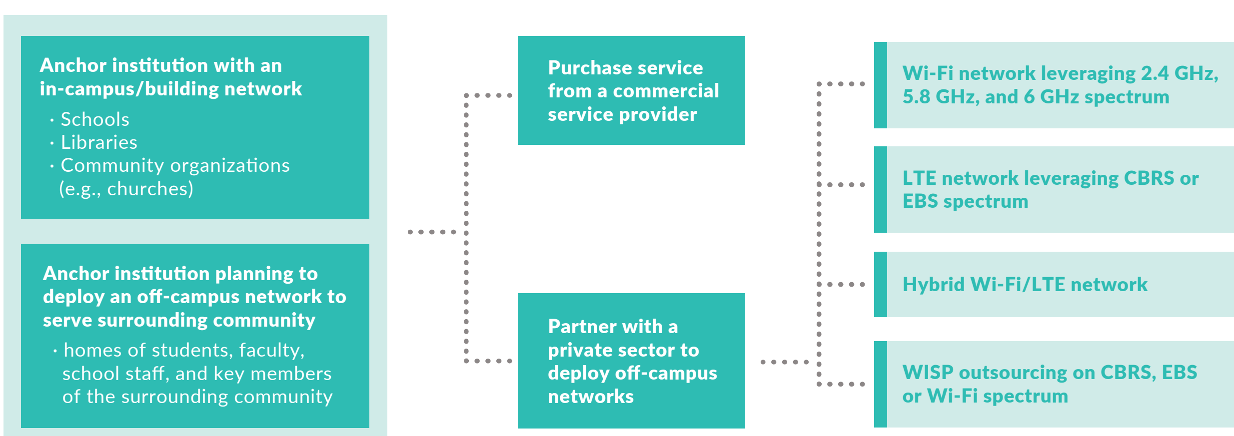
Further, the final decision on wireless technology or the scope of a deployment can, in some cases, entail a combination of two options. For example, if the owned network cannot fulfill the full coverage of the target community, the anchor institution might choose to purchase service from a commercial 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



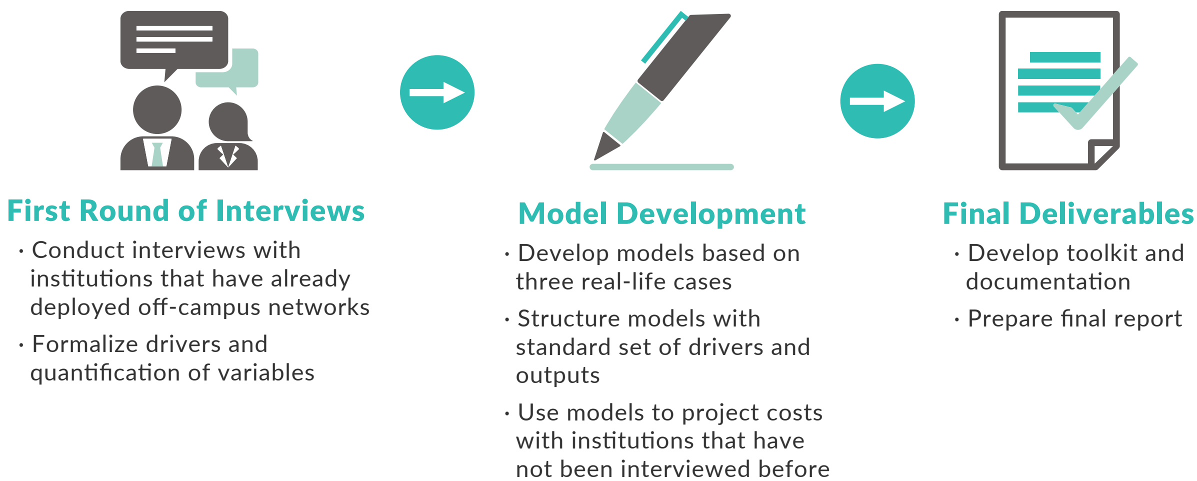
Source: Telecom Advisory Services analysis

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	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

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

STRUCTURAL OPTIONS

TECHNOLOGY 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	Socio-economic variables
	Number of students that have internet access at home	
	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.

	DRIVER	EXPLANATION/RATIONALE
SERVICE LEVEL REQUIREMENTS	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.

APPENDIX B

The "To and Through" Opportunity: Case Studies of School and Community Networks Able to Close the Homework Gap for Good

See Attached Case Studies

AUGUST 2022

THE "TO AND THROUGH" OPPORTUNITY:

Case Studies of School and Community Networks Able to Close the Homework Gap for Good

By Matthew Marcus and Michael Calabrese
Open Technology Institute at New America

SHLB
SCHOOLS, HEALTH & LIBRARIES BROADBAND COALITION

OPEN TECHNOLOGY INSTITUTE

ACKNOWLEDGMENTS

We'd like to thank the dozens of school, library and local government officials who generously offered their time and expertise to make our case studies possible. Likewise, many of their private sector partners and vendors, including wireless internet service providers and network integrators, helped us understand the technical variations and tradeoffs reflected in the diverse case studies we describe here.

About the Authors

Matthew Marcus is currently a Federal Broadband Program and Policy Analyst with the State of Wisconsin's Broadband Office. Until recently he served as a policy analyst and graduate student intern at OTI's Wireless Future Project, where he conducted in-depth research and dozens of interviews with school districts, local government officials and private companies involved in deploying or supporting the school and community networks profiled in this report.

Michael Calabrese directs the Wireless Future Project at New America.

Thanks as well to **Amir Nasr**, the former senior policy analyst at OTI's Wireless Future Project, who assisted with research and interviews during this year-long project. Thanks as well to the OTI's Comms team - **Austin Adams** and **Michelle Siegel** - for their helpful review and edits.

OPEN TECHNOLOGY INSTITUTE

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.

SHLB
SCHOOLS, HEALTH & LIBRARIES BROADBAND COALITION

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.

INTRODUCTION

Even before the COVID-19 pandemic led to school shutdowns and a shift to remote learning, deep inequities hobbled the ability of schools and teachers to take full advantage of digital learning tools. In the spring of 2020, an estimated **17 million K-12 students** lived in households without broadband internet access, including one out of three Black, Latino and Tribal households nationwide. The pandemic turned this pre-existing "homework gap," as now-FCC Chairwoman Jessica Rosenworcel has long described it, into a remote learning crisis, as New America explainedin a 2020 report **The Online Learning Equity Gap**.

Our two organizations joined with other leading educational equity advocates to **petition the FCC** in January 2021, asking the agency to permit E-rate funds to pay for off-campus internet access. Before the FCC could act, Congress answered the call by creating the $7.17 billion Emergency Connectivity Fund (ECF) in the spring of 2021.

ECF allows schools and libraries to providestudents and patrons with affordable internet access and devices. However, this Emergency Connectivity Fund is expected to be exhausted by the end of 2022.

Our organizations are concerned that there is still no long-term solution to the "homework gap." Once the ECF program ends, millions of students will be unable to complete online assignments or explore new interests without home internet.. The homework gap not only worsens educational inequities; it lowers the quality of education for all students when teachers refrain from assigning homework that requires internet access or digital tools that a substantial portion of the class lacks.

One silver lining is that the pandemic served as a catalyst for dozens of innovative school districts and local communities to initiate or expand wireless broadband networks that connect student households directly to the school's network. This report provides in-depth profiles of 12 networks that are well on their way to closing the homework gap for good. These 12 were selected from among more than 40 piloted or completed community anchor networks and related initiatives that we have identified. School districts, library systems, and local governments sponsoring these networks are using a variety of wireless technologies and partnership models to deploy connections primarily for the purpose of providing students with internet access at home and in other key locations after school hours.

All of these networks rely on free access to the public airwaves ("spectrum") that the FCC has recently made available. The community anchor networks profiled here use a variety of shared use frequency bands depending on their local circumstances: Wi-Fi, operating on unlicensed spectrum; private LTE, operating on Citizens Broadband Radio Service (CBRS) spectrum or (less commonly) on the licensed Educational Broadband Service (EBS) band; and TV White Space (also less common), which is a longer-distance but lower-capacity form of Wi-Fi that uses unlicensed TV channels in rural areas.

For each case study, we have tried to explain the rationale for the school district's choice of wireless technology and corresponding spectrum. In one notable case, the Lindsay Unified School District – a predominantly low-income, agricultural community in California's Central Valley – provides coverage and a free, reliable internet connection for every student household by combining all three of major technologies: Wi-Fi, CBRS, and EBS.

Although the case studies are grouped in three categories based on wireless technology (Wi-Fi, CBRS and Hybrid/EBS), collectively they represent a wide variety of funding, sponsorship and business models. For example, the very low-cost and extensive mesh Wi-Fi networks deployed by the school districts in Council Bluffs (IA) and in San Jose (CA) are far less expensive and more sustainable than purchasing subscriptions from commercial internet providers, in part because their local municipality is a partner and offers free or very low-cost access to both street light poles (to mount wireless transmitters) and to the city's fiber network for data backhaul.

In contrast, several school districts in Texas (Castleberry, Fort Worth, McAllen) have contracted to build and own their own network using shared CBRS spectrum, including by erecting new cell towers to extend coverage from the rooftop of public buildings (mostly "schools as towers"). Harris County (TX) has taken this approach, forging a unique example of a county-led initiative that coordinates the engagement and assets of nine local school districts and the public library system. In Fresno (CA) the school district is already covering 25,000 mostly low-income student households by using "schools as towers" to locate CBRS wireless access points.

In some other cases, such as in Boulder (CO) and in Val Verde (CA), school districts have partnered with a local private Wireless Internet Service Provider (WISP) to reduce their own costs and risks. In Fontana (CA) the school district agreed to be the anchor tenant on a new CBRS network that will be owned and operated by Kajeet, a private network operator.

Finally, it is important to view these case studies in the context of the companion economic study our two groups are releasing simultaneously: **The To and Through Opportunity: An Economic Analysis of Options to Extend Affordable Broadband to Students and Households Via Anchor Institutions.** The study, by Dr. Raul Katz, a prominent telecom economist, demonstrates that deploying wireless network connections "to and through" anchor institutions is often the most low-cost and financially sustainable option to connect households in unserved and underserved areas. Dr. Katz also provides a 'Toolkit,' which we plan to make available soon online, that will allow schools, libraries and others to calculate the costs and tradeoffs among the different major options for connecting students and others in the community.

Together, we hope these reports encourage policymakers to support these school and community networks, which could go a long way toward permanently solving the homework gap and improving the quality of education for all.

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

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

CONTENTS

Wi-Fi Networks: Leveraging Unlicensed Spectrum

East Side Union High School District (ESUHSD) - San Jose, CA

Network Lead: Randy Phelps, Chief Technology Officer

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
22,576	Students: 1,600	5 GHz unlicensed	Students: 20/20 Community: 10/3	Approx. $2.7M ($9M total)	Approx. $60,000	ECF (applied)

Unique Qualities

San Jose's ESUHSD is a well-established example of the substantial benefits of close collaboration and partnership between a school district, a municipality and a private company with expertise in planning, installing and maintaining community wireless networks. ESUHSD initiated network planning and deployment with proceeds from a public bond. As part of its "Wi-Fi for Everyone" partnership, the City of San Jose provides the fiber backhaul, siting and electricity (mostly street light poles) for the access points (APs) that make up the Mesh Wi-Fi network blanketing much of the district and the low-income east side of the city. In return, ESUHSD allows community members to access the network on a more capacity-limited basis.

ESUHSD paid for the installation of the network, relying on a turnkey contract with **SmartWave**, a third-party integrator that installed and maintains the network (as it does the Council Bluffs CSD network also profiled here). ESUHSD covers ongoing operating and maintenance costs with the money saved by switching students to all-digital textbooks. The network provides unthrottled connections to students' homes, while connections for the community (who sign in through a separate service set identifier, or SSID) are limited to 20/20 Mbps. This partnership model has enabled ESUHSD to ensure robust coverage for students and essential basic connectivity for community members thanks to a very cost-effective mesh Wi-Fi network. The network will be the largest city-owned community wireless broadband network in California when completed in 2023.

Motivations & Background

"Buying bricks [cellular hotpots] is like buying a six-pack of water, rather than giving the town a water pump." - Randy Phelps

Randy Phelps, the Chief Technology Officer at San Jose's ESUHSD, has been operating the network in collaboration with SmartWave Technologies for over five years. He emphasizes that the foundational motivation continues to be to ensure all students have adequate and reliable access to the internet and technology for educational purposes. Around two-thirds of ESUHSD's student population are considered socioeconomically disadvantaged. An estimated 30 percent of students in the district lack broadband internet at home and most of the students are eligible for the district's free or reduced lunch program. ESUHSD is one among a small handful of networks that began addressing the “homework gap” by extending connections to students at home prior to the pandemic. As a result, the district adapted more easily to remote learning when schools were forced to close temporarily in the spring of 2020.

Once the district settled on the goal of ensuring their students had reliable internet for digital learning at school and at home, ESUHSD concluded that constructing their own Wi-Fi network was more financially sustainable than other connectivity options. In the long-term, ESUHSD determined that monthly subscriptions for mobile cellular hotspots would be less reliable (due to varying signal strength) and more expensive than building out a Wi-Fi network. The financial viability of the network in San Jose is a product of the district’s beneficial partnership with the city of San Jose and SmartWave, as well as strategic funding decisions—such as transitioning to all digital textbooks, which generate a savings that covers the annual operating costs for the network (as it does for the Lindsay USD, also profiled here).

Although much easier logistically, ESUHSD concluded that the cost of distributing and relying on MiFi hotspots in the long-run—beyond subsidized trial periods—was financially infeasible, especially when considering the lower bandwidth and uneven indoor coverage they offer. Phelps noted that paying monthly subscriptions for students would be much too costly, especially if the hotspots were equipped with unlimited data usage plans. He also noted that hotspot devices have to be replaced more often and need to be charged regularly – a small but additional hurdle for some students and households. In contrast, Wi-Fi APs transmit directly to student Chromebooks in any location within range and without the need for customer premise equipment (CPE)—such as an external antenna, hotspot or plug-in router—to receive and rebroadcast the signal to the student device via Wi-Fi. Overall, ESUHSD determined that a Wi-Fi network with meshed APs would be more financially sustainable, have much more capacity, and serve the community as well as students. Crucially, the project also held the potential for expansion to other communities in need, which is an ongoing effort by San Jose and its schools.

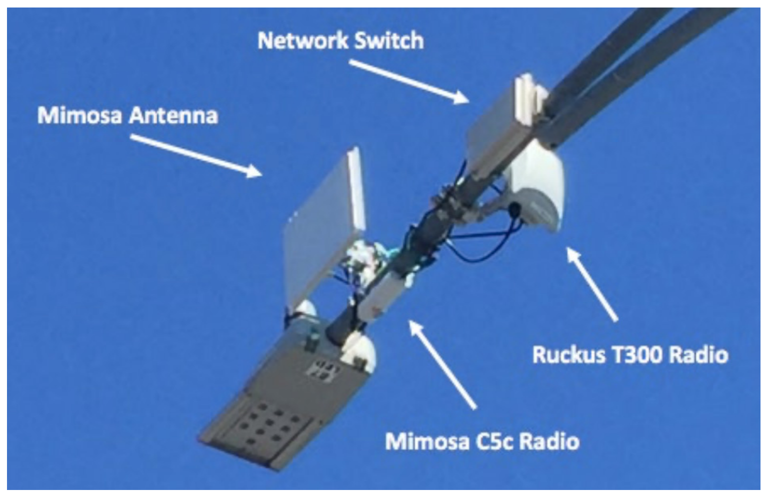
ESUHSD has a total of 11 comprehensive high schools and eight smaller alternative schools, together serving over 22,500 students. Phelps and his team began by informally assessing need through discussions with students, families, and teachers. Unsurprisingly, students lacking internet connectivity lived in lower-income households where cost is the primary barrier to broadband connectivity at home. ESUHSD’s working group also determined that there are two high schools with generally more affluent students and high connectivity rates, and thus they decided not to extend the network to serve those areas.

In order to target student’s homes most effectively for the first phase of the network buildout, ESUHSD collaborated with K-8 schools to aggregate and overlay maps showing where low-income students lived. These maps were used to determine the most strategic spots to locate APs in the James Lick High School attendance area, which corresponds to an area of very high need (see maps below). In the summer of 2021, the district replicated this targeted mapping process for Overfelt and Yerba Buena High Schools, which are both now fully covered. The remaining five schools of the eight total that will be connected are planned to be completed by 2023.

Technology

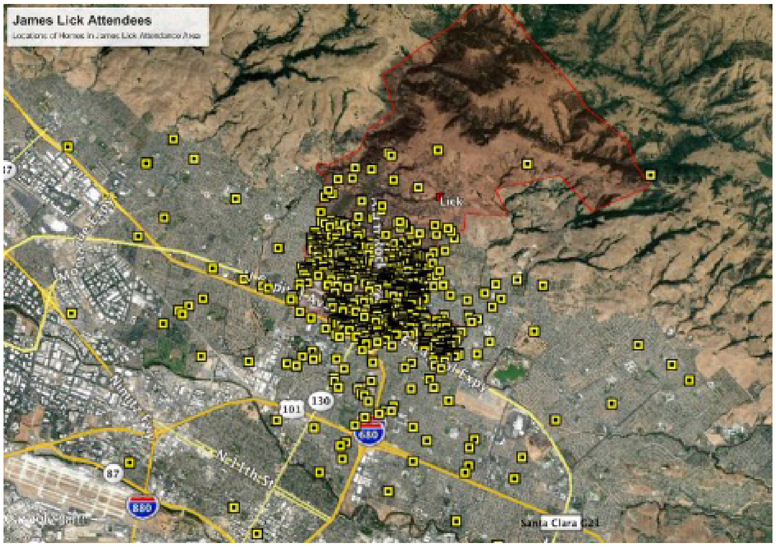
The topography and density of the district's neighborhoods makes a meshed Wi-Fi network a strong option for providing connectivity to the student population and community. Operating in the unlicensed 2.4 GHz and 5 GHz spectrum, ESUHSD has strategically installed hundreds of high-capacity APs on existing city infrastructure (primarily street light and traffic signal poles, as pictured below). The city provides electricity to the poles—which also power the APs—as well as the fiber backhaul where available. In the James Lick High School attendance area, the city had fiber installed, which facilitated the quick roll-out of ESUHSD's first phase of the network. In the neighborhoods where students from Yerba Buena and Overfelt High Schools live, the city has a fiber conduit, but no actual fiber in the ground. ESUHSD and the city have decided to split the costs of that fiber installation—a one-time fee—and ESUHSD will have access to that fiber long-term for other purposes as well. Where fiber isn't available, SmartWave deployed 24 GHz and 60 GHz millimeter wave technology to supplement the fiber to provide high-capacity backhaul for the mesh Wi-Fi infrastructure.

For each attendance area, Phelps and his partners at SmartWAVE continue to consult their socioeconomic mapping of student households to locate the APs. For the James Lick High School attendance area, they installed 211 APs, while the Overfelt and Yerba Buena attendance areas each have about 220 APs. The district is using enterprise-class APs that they report are rarely offline due to malfunction and that they estimate could be operational for as long as ten years. In these urban neighborhoods, each AP covers an area of approximately 1,000 square feet. The mesh Wi-Fi architecture facilitates high-capacity throughput, but also requires a relatively high density of APs because the APs (mounted on street infrastructure) are close to the ground and because, by law,Wi-Fi power levels are low. This reflects an inherent tradeoff for Wi-Fi networks: The APs are relatively inexpensive and deliver very high throughput, but the density of deployment is high because the transmit power using free unlicensed spectrum is low compared to licensed spectrum.

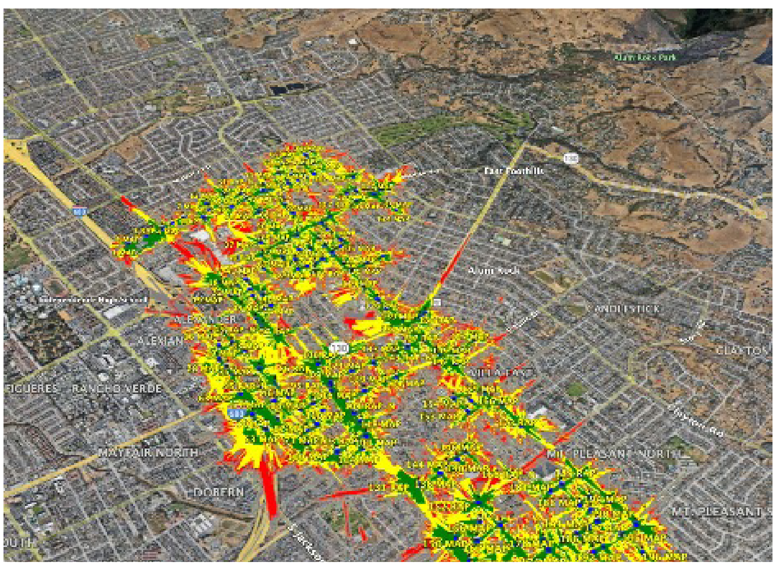


Light pole AP installation in East San Jose
Source: Telecom Advisory Services analysis

Students connect directly to the APs via Wi-Fi using school-provided devices (typically Chromebooks) that use a separate SSID ("service set IDentifier"—a 32-character code that uniquely identifies a wireless network) distinct from the community access portion of the network. This ensures security and CIPA compliance. It also ensures student priority for capacity on the network Currently, students at home are averaging download/upload speeds of at least 20/20 Mbps. Students have unlimited data capacity and connections are never throttled.



Yellow markers indicate student households in the James Lick High School attendance area. **Source:** smartwave.us



Heat map of the James Lick High School attendance area. Blue dots with accompanying yellow text indicate APs. The heat map colors signify propagation levels, green being the highest level (strongest signal) and red the lowest. **Source:** smartwave.us

The school network has yet to see any congestion issues and Phelps reports that they are using about 40 percent of network capacity on the school-side of the network. The city throttles the community connections to 10/1 Mbps—a strategic decision by the city, aimed at avoiding congestion on the community-side of the network. In addition, throttling community connections also mitigates concerns that the city's free network is a close substitute for incumbent ISP services.

ESUHSD's Wi-Fi network is reaching about 75 percent of students in targeted neighborhoods. The district provides students outside of that coverage area mobile hotspots as needed. The district continues to qualify for Sprint's **One Million Project** and distributes Sprint (now T-Mobile) hotspots to students in need. In addition, the district buys hotspots from AT&T to test which hotspots work best in each neighborhood. Phelps noted that many very low-income students move multiple times during a school year—ESUHSD has more than 1,000 students that move about five times in one school year. These students often require a different mobile carrier's hotspot depending on the neighborhood they relocate to. The mobile hotspots also serve as a backup connectivity option, and many students have them, but use them much less frequently than the meshed Wi-Fi network.

Impact

Based on student self-reporting, approximately 75 percent of the students being targeted are receiving consistent and robust Wi-Fi coverage. ESUHSD's student network is experiencing about 60,000 unique connections per day—the district has nearly 23,000 students and most have more than one device. Over the course of a month, the network experiences 15 to 18 terabytes of data downloads, which Phelps noted is equivalent to the Library of Congress' network activity

Based on student self-reporting for the three schools that have been deployed, ESUHSD has found that about one-third of students and their families are connecting to the internet solely through ESUHSD's network and using it for all of their internet needs. Another one-third use the network for some access to the internet. Phelps also noted that many teachers use the network at home—another **factor** that is important to ensuring students have a quality educational experience.

During the 2019-20 school year, like much of the country, San Jose's ESUHSD closed for in-person instruction and quickly transitioned to remote learning. Fortunately, they were well prepared and were able to adapt with relative ease. The combination of the deployed Wi-Fi network in low-income parts of the district and the distribution of mobile hotspots ensured that students could attend class remotely. Despite the remote learning environment, online attendance was quite good, at 83 percent. As most school districts across the country concluded, many students suffered academically during the abrupt transition to online learning. Phelps said that while remote learning is far from optimal, about 30 percent of the students at ESUHSD had their most successful academic year in 2020-21. Of course this is not solely because of the district's Wi-Fi network, but it very likely facilitated a more supportive, interactive, and engaging online learning environment. This also highlights the reality that some students may be more successful in remote environments than in classrooms. Having connectivity for learning after school hours—and closing the "homework gap"—is increasingly critical for educational equity, as is the resilience of a 24/7 connection to the school's network and access to other online resources, especially for students with differing learning environment needs or preferences.

Cost & Funding

The full network build-out cost for nine high schools and the lower-income neighborhoods they serve is projected to be approximately $9 million. Thus far, the initial three high schools connected cost $2.7 million in capital costs, most of which the district raised in 2014 through a school technology bond approved by local voters. ESUHSD first began deploying Chromebooks and upgrading on-campus Wi-Fi following the passage of the technology bond. They quickly learned that they needed to connect students at home, so they pivoted their efforts to an off-campus wireless network. The initial Wi-Fi pilot launched in 2017, and the district, city, and SmartWave have been operating it successfully since, extending the network to additional attendance areas.

Most of the build-out cost is focused on the purchase and installation of the Wi-Fi APs, which includes wiring both fiber backhaul and electricity to the APs. The district's costs are substantially lower because of its partnership with the City of San Jose. Because light poles are fairly ubiquitous, the APs can be deployed densely and strategically. Although the city charges commercial providers permitting fees to mount equipment on city street lights and traffic signal poles, those fees are waived for this joint school/community network.

For example, the municipal permit fee per light pole to install a commercial AP in San Jose is roughly $990, which the city waives and classifies as in-kind funding for the entire ESUHSD network. This fee waiver alone saved the district just under $650,000 for the first three connected attendance areas. Of course, unlike commercial deployments, the school network in San Jose is also providing a public amenity and likely would not have been able to pay such fees for pole attachments (see the profile of Fresno USD, which opted for an entirely different network architecture after the city denied permission to mount APs on city light poles).

In addition to waiving these fees, the city provides fiber backhaul to the APs where it is available, as well as electricity to the APs, all at no cost. The school district pays for any wiring needed for connecting the APs to the electricity sources, which their private contractor (SmartWave) installs. As noted earlier, in areas where city fiber isn't available, the city and district have agreed to split the costs evenly for installing fiber at those locations. As noted earlier, in areas where city fiber isn't available, SmartWave uses high-capacity wireless technology for backhaul where fiber build-out costs are exorbitant.

The APs the district and SmartWave install are sold by Ruckus Wireless and cost about $320 each. Planning and installation of the network is a larger share of initial deployment costs. Al Brown, CEO of SmartWave, explained that the maintenance of these APs and of the network as a whole costs roughly six percent of total build-out cost each year. Future network costs are very manageable, Phelps said, consisting of ongoing maintenance and marginal AP upgrades on a rolling basis. The district believes the APs could have a lifespan of ten years and they forecasted that the replacement costs will be about 20 percent of the overall cost of the installation. As an example, he noted that replacing and upgrading APs in the first attendance area cost around $340,000, as compared to over $1 million for the initial install. Importantly, Phelps said the partnership with SmartWave – which provides the technical expertise, conducting all of the maintenance and installation—reduces the district's needed technical capacity, and allows Phelps and his counterparts to focus on other important components such as planning, outreach, and day-to-day operations.

The installation of the network for the first three high school attendance areas was funded entirely through the initial $2.7 million tech bond and the district has approved municipal funding for the build-out of the additional six high school attendance areas. The City of San Jose has approved $5.9 million for the remaining six schools, but Phelps and his team predict it will cost closer to $5.3 million. Phelps and ESUHSD also applied for assistance through the American Rescue Plan Act of 2021's Emergency Connectivity Fund, and are expecting to get some federal funding soon. The district does not use any E-Rate funding for the network. Phelps noted in the design and planning stages, they found they had enough funding to build the network without using E-Rate and without being beholden to its cost-allocation and other restrictions regarding off campus internet provision.

Challenges

The meshed Wi-Fi network is producing consistently good results and, as noted, students and teachers are making roughly 60,000 unique connections each day. Of course, there are challenges. Phelps highlighted a common challenge for all wireless internet networks: achieving sufficient data throughput rates indoors to support real-time interactive video streaming. Some students have reported difficulty Zooming in certain parts of their homes, and they've found this is especially true when students are in interior spaces of homes with multiple walls acting as barriers to the exterior AP signal. Students find they often need to move to an exterior-facing room, or closer to a window, since their Chromebooks are receiving the Wi-Fi signal directly from the APs.

Phelps explains that the network was designed to account for density in locating APs and so that at a minimum, students receive signals that have the strength to penetrate an exterior wall of the home. That said, they are still working through these hurdles with a small group of students that are experiencing difficulties. Often it is as simple as relocating their device within the home (e.g., closer to a window); but ESUHSD has also started offering extender devices that plug into electrical outlets and extend the Wi-Fi signal more effectively to interior portions of the home. The district is not yet offering to install external antennas (CPEs) as some districts are doing (see the profile for Lindsay USD's hybrid network approach). As a fallback, the district has purchased cellular hotspots that can be issued to students as needed, as noted above.

Going Forward

ESUHSD and SmartWave plan to have the remaining six attendance areas covered before the start of the 2022-2023 school year. As of May 2022, they had four schools completed with four remaining to bring online in Phase 1. At completion, the network will consist of approximately 3,200 APs that provide coverage to around 22,000 student households, including students attending schools that feed into the high school district.

Within San Jose's East Side Alliance Network, ESUHSD is expanding the network to additional K-8 districts. The eight districts will be deploying school-to-school fiber, and SmartWave and ESUHSD will be branching out Wi-Fi along these corridors. The K-8 districts had originally sought out quotes from other private ISPs to build out a similar network, and were given build-out estimates roughly $200,000 more than the cost ESUHSD believes is needed to complete the build-out. They are currently finalizing the contracts, but the agreement as it stands is that the K-8 districts will pay an initial build-out cost and a portion of the ongoing maintenance costs for the school side of the network. ESUHSD and SmartWave are also providing the district with all the necessary accounts and identity management tools to ensure security and functionality on the school network.

Key Takeaways & Success Factors

- Partnering with the city to leverage existing public assets, such as street lights (for siting APs) and fiber (for backhaul), greatly reduced the overall cost to build and operate the network.
- A mesh Wi-Fi network is extremely cost-effective and provides far more total data capacity than other options provided that schools (or other community anchors) have access to siting at low or no cost—ideally street furniture, but also public buildings.
- ESUHSD and the city hired a firm with extensive outdoor wireless design, modeling and implementation experience following a methodology that had proven successful in other areas.
- ESUHSD employed a "phased" approach, modifying the design and deployment of each successive phase based on the performance of the previous phase—what the district calls a "success based" approach.
- Firm, unwavering commitment to serving people who need the services and developing relationships with stakeholders (particularly the municipality) is paramount.
- Cooperating with partners and listening to users is critical—issues will arise and their team learned to accept, adapt and overcome challenges.

Council Bluffs Community School District, “BLink-Bluffs,” Council Bluffs, IA

Network Lead: John Stile, Chief Technology Officer

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
8,500	Approx. 7,500	Unlicensed	10/10	Approx. $2.4M	Approx. $120,000	ESSER

Unique Qualities

The Council Bluffs Community School District initiated the BLink-Bluffs (“BLink”) free community Wi-Fi network, in partnership with the City of Council Bluffs, Iowa, that traces its origins back to 2014, making it one of the first K-12 school networks of its kind. Because the district began steadily expanding the network during the years prior to the pandemic shutdown in 2020, its students were equipped for remote learning, and are almost completely protected from the homework gap that persists in other Iowa districts today. BLink represents an important case study as a city-school district partnership and as a mesh community Wi-Fi model. The BLink network currently covers about 85 percent of the district’s students and a similar share of the community. The BLink network has not only been a boon for students and educators, but also for community access to telehealth and other important applications.

Motivations & Background

The school district initially decided to create the network after Google contributed 500 Chromebooks for the original trial called **Project 500**. The school district then purchased Chromebooks for all high schools and eventually for all Council Bluffs K-12 students. The educators quickly discovered that integrating digital learning components into lessons and homework wasn’t feasible given the large number of students without broadband access at home. The city was already providing free Wi-Fi to some public spaces and agreed to partner with the Council Bluffs Schools to build a joint network to both connect student households and serve as an amenity and backup network for the community.

As described in OTI’s previous report—**“The Online Equity Learning Gap”**—the BLink network is being built out neighborhood-by-neighborhood in twelve stages. BLink has completed eight phases (see map here) and currently connects 85 percent of the Council Bluffs Public School District’’s students. The network is also being extended into the neighboring district, Lewis Central Community School District. Where financially and technically feasible, the deployment prioritized high-poverty areas where the largest shares of students had no internet in their homes.

The partnership between the district and city reduced many of the build-out hurdles other networks have faced. The city contributes fiber backhaul for the network, provides locations for mounting access points (APs) on streetlight poles and other public infrastructure, and the utility and subscription costs are shared by the city and the district. In exchange for this ongoing support, the district structured the network to offer connections to anyone in the community who logs on in covered areas. Students are automatically authenticated when they connect using their school-issued Chromebook. The network for both students and community is limited to 10/10 Mbps to each connection, which adequately supports online learning activities such as video streaming and remote learning applications, but also ensures there is sufficient bandwidth to serve all connections.

The BLink network has proven to be a successful public-private partnership that shares risk as well as responsibilities among government entities. The school district raised the funding for initial deployment and handles the overall management of the network, particularly business-related tasks, such as contract administration. The city's technology team assists with network monitoring and general maintenance. In addition, the partnership receives philanthropic support from Google and the Iowa West Foundation, both of which serve on the governance committee. Google has also assisted in spot-checking network deployments and providing analytics. SmartWave—a wireless networking firm—is under contract to complete the network build-out, as well as to conduct maintenance and troubleshooting. The district and the city evenly share the operating costs, most of which pays for SmartWave's contracted operating, upgrade and maintenance services.

Technology

The BLink network operates entirely on unlicensed Wi-Fi spectrum in the 5 GHz frequency band, although it is expected to expand its capacity by upgrading over time to incorporate the new 6 GHz unlicensed spectrum that will be available for outdoor deployments by mid-2023. The district contracts with SmartWave, a full-service wireless network integrator with extensive experience installing and maintaining complex wireless networks for schools, municipalities, and similar partnerships (such as San Jose East Side Union High School District's network, also profiled here). The network uses Ruckus Wireless equipment for the APs, and students connect directly to the APs from their devices. Jose Hernandez from SmartWave is shown below mounting a bracket to one of these APs for the Carter Lake extension of the network. To extend the reach of the mesh network and provide network backhaul, the network uses a variety of point-to-point (PTP) and point-to-multipoint (PtMP) wireless links where fiber is not available. All meshed PTP/PtMP backhaul relies on unlicensed 5GHz spectrum, helping to reduce costs.

A bracket being mounted on a SmartWave AP.
Source: Council Bluffs School District

John Stile, Chief Information Officer, explained that the deployed Ruckus APs have a useful lifespan of seven to ten years, and that most of the equipment deployed for the first phase in 2014 is still operational with no technical issues. To date, the district has deployed about 640 APs, each being 300 to 450 feet apart depending on tree cover (since heavy foliage reduces the range of wireless signals). The capacity and quality of the APs will be greatly enhanced as they are upgraded to the new Wi-Fi 6E standard that will operate on the newly-available and far larger 6 GHz unlicensed band.

BLink uses two separate service set IDentifiers (SSIDs) for school and community connections to the network. Students and educators are automatically authenticated and connected to the district's protected network through the school SSID with their school-issued Chromebooks. The Chromebooks have device-level content filtering enabled, using programs such as Umbrella and Securely to further ensure proper security and **CIPA** compliance. The community connections use a separate SSID and require community members to log in, and agree to terms of service before going online.

Impact

The network serves about 7,500 student households. Stile said that BLink experienced an explosion of bandwidth consumption during 2021. On average, the network (school and community users combined) consumes about 40 terabytes of data per month. BLink—working with volunteers from local Google offices—found that on average, 80 percent of the activity on the network in the first phases of the deployment was school- or learning-based. Stile highlighted that during the 2020-21 school year, the district needed to provide very few carrier hotspots to students outside of the network coverage area due to lack of an adequate internet connection.

In addition to its measurable success at increasing the number of connections and usage of the network, Stile noted that compared to other urban districts in the area, the district's schools have had much better educational outcomes since deploying the BLink network. Stile notes these improvements could be the product of multiple and less-observable factors, but the deployment of the network tracks with the notable improvements. This echoed the findings of the Lindsay (CA) Unified School District (also profiled here), which has a similarly long track record of deploying and connecting low-income students with Wi-Fi at home prior to the pandemic.

The community side of the network has been a valuable asset during the COVID-19 pandemic. It ensured that most Council Bluffs residents had a connection to the internet for vital telehealth services and access to crucial public and personal health information online, along with other information and services. Stile highlighted that the network experienced substantial use for COVID-19 testing inquiries and appointment setting, as well as for seeking out and scheduling vaccinations.

.

Cost & Funding

The capital costs for the mutually-owned and managed network were approximately $300,000 for each phase, with the total cost for the eight phases estimated to be approximately $2.4 million. The city and school district have expanded from their original eight-phase plan to include a new total of 12, which will primarily involve connecting a neighboring school district (details provided in the "Going Forward" section). As noted above, Stile and the district believe each phase's respective equipment will have seven to ten years of useful life, so necessary updates will happen slowly in phases, based on need.

The operating cost for the network is currently $100,000 annually, split evenly by the district and the city since the network serves both students and the public. The majority of this cost is for SmartWave's maintenance, troubleshooting, and build-out services. Currently there are 640 deployed APs with 630 poles. The operating costs for the APs is roughly $32,000 per year for electricity and pole locating fees to the city. The city subsidizes the cost of electricity to the poles, and Stile explained that the electric company reclassified the district as a wired carrier instead of a mobile carrier, thereby decreasing the annual fee for locating on poles.

The school district does receive E-Rate funding—both category one and two—but as noted by the former CTO in **OTI's November 2020** report, the inflexibility of the current E-Rate rules prohibits discounts for the cost of Wi-Fi (or any technology) to extend connections to students off school property—even though the district pays a fixed price for fiber, and the network would otherwise be inactive during non-school hours. Access to the city's fiber for backhaul avoids the burden imposed by E-Rate cost allocation rules, since it backhauls student and teacher educational data generated off campus. Moreover, E-Rate's restrictions have required unnecessary IT upgrades to ensure the district doesn't violate eligible-use rules when designing the BLink school-to-home portion of the network.

Stile explained that the district considered the cost of directly connecting students over a three-year period, and how that compared to the cost of paying for monthly subscriptions for mobile carrier hotspots. The overall cost of providing hotspots to students with an adequate data package, comparable to the BLink network's capabilities, would be approximately $40 per month, or $1,440 per student for a three-year period. The BLink network, as it stands, costs about $10 per month per student connection, or $368 per student for a three-year period—as well as providing valued connections to the community, and avenues for long-term expansion to other parts of the region.[1] Those costs decline further given the actual useful life of Wi-Fi APs, which is considerably longer than three years. The savings from the BLink network compared to hotspots would be even more pronounced if E-Rate allowed funding—or at least gave the district flexibility within its current funding—to help offset the costs of extending school networks to students' homes and to use existing school fiber connections for backhaul.

[1] SmartWAVE provided the following calculation: as of July 2022, $2.4M for capital costs and $120,000 per year for operational costs (for three years $360,000) which brings the total cost of operation to $2,760,000 for three years. This total divided by the total number of students (7,500) equals $368 per student for a three-year period, or $10 per month per student.

Challenges

As other school districts have similarly opined, Council Bluffs found that even though the BLink network closes the homework gap completely and sustainably, it didn't initially qualify for the Emergency Connectivity Fund (ECF) because it is not a subscription-based service. FCC rules interpreting the ECF statute only permit reimbursements for network infrastructure to connect students in geographic areas that are completely "unserved" by commercial internet service providers. The district could not demonstrate that substantial portions of the district are unserved by traditional ISPs, even though many households rely on slow DSL service and the signal strength of mobile carrier services is often too weak to support remote learning indoors in low-income and exurban areas. The district did receive approval for ECF reimbursement for devices in July 2022.

Concerning network design, the main connectivity challenge is reaching student households in multi-dwelling housing units. Stile explained that many of the buildings' management companies would not allow them to install or locate equipment on the premises to ensure the signal reached units in harder to reach interiors of buildings. For those student households, the district resorted to providing mobile carrier hotspots, but it continues to explore better options for these families. Stile noted that potential upgrades to Wi-Fi 6E APs may help remedy this challenge in the future, but given the unknown length of time before that becomes a viable upgrade (affordable standard power Wi-Fi 6E equipment for outdoor transmission may not be available until mid-to-late 2023), they are working to improve connectivity for these households within their existing system.

Going Forward

The expansion of the BLink network, phases nine through 12, are underway. The primary purpose of this expansion is to connect neighboring Lewis Central Community School District, which serves a different portion of Council Bluffs. That district is another high-need community, with more than 40 percent of the district's approximately 3,000 students considered low-income. This buildout is expected to be completed by 2025. The Council Bluffs School District and the city are still working out the details on how Lewis Central will help fund the build-out and the ongoing maintenance.

Stile explained that they are looking forward to the availability of high-capacity Wi-Fi 6E (likely in mid-2023) and the option to upgrade BLink's APs, which will not only increase speeds and overall network capacity, but also allow for more connections to each AP, reducing the total number needed. Stile noted this could result in a major cost reduction, particularly in less densely-populated neighborhoods, and generate further savings as the price of Wi-Fi 6E APs decreases over time. The district doesn't have any current plan to replace existing APs, but it will start by replacing the APs from phase 1 (deployed in 2014). Stile also noted that upgrading APs will mostly follow this trajectory of replacing the oldest equipment first, but that they will also be strategic about replacements. If some existing APs are functioning well and serve a small number of households, another AP that was deployed more recently but serves many more households and requires greater capacity may be upgraded first.

Key Takeaways & Success Factors

- CBCSD is providing connectivity using a Wi-Fi mesh network for approximately one-third the cost of a mobile carrier subscription MiFi hotspot solution.
- A mesh Wi-Fi network has proven to be extremely cost-effective and provides far more total data capacity than other options, in substantial part because the district's partnership with its municipality allows it to leverage public assets, including access to city fiber for backhaul and street light poles for hundreds of Wi-Fi access points.
- In addition to the 7,500 students, the network provides Internet service to over 60,000 unique clients per month in the community.CBCSD deployed in a phased approach that prioritized the poorest neighborhoods, modifying the design and deployment of each successive phase based on the results of the previous phase and available funding.
- CBCSD and the city created a non-profit consortium that includes corporate (Google) and non-profit donors (Iowa West Foundation) that contribute funding, as well as technical and administrative expertise.
- CBCSD and the City of Council Bluffs have also extended its BLink network to cover the neighboring Lewis Central CSD by creating a "Wi-Fi Consortium" agreement between the two school districts and their municipalities, aimed at sharing resources and costs. This will provide seamless network coverage for students that move between the adjoining districts, as well as for residents in the greater Council Bluffs area.
- CBCSD hired a wireless networking firm with extensive outdoor wireless design, modeling and implementation experience based on an architecture and methodology that had been proven successful in other areas.

North Carolina Department of Public Instruction, Hyde County, NC (TVWS+Wi-Fi)

Network Lead: Ray Zeisz, Senior Director, Friday Institute, NC State University

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
Approx. 600	30	TVWS (15 channels, 90 MHz)	High 45/25 Median 20/17 Low 7/3	$60,000	Included in the CAPEX	CARES Act

Unique Qualities

Hyde County's Wi-Fi and TV White Space (TVWS) wireless network is a unique joint effort led by North Carolina State University's Friday Institute for Educational Innovation, in partnership with Hyde County School District and RiverStreet Networks, a local wireless internet provider (WISP). The Hyde County SD network is one of three wireless initiatives spearheaded by the Friday Institute to investigate technology capabilities, as well as cost models, operational characteristics, and the sustainability of technology. Hyde County is located on North Carolina's coast and on the Outer Banks, where little telecommunications infrastructure exists. The TVWS portion of the network serves student households that are rural or lack the line-of-sight necessary for more conventional fixed wireless services. Point-to-multipoint Wi-Fi will eventually be co-located where TVWS radios are mounted to reach accessible homes. TVWS propagates for very long distances compared to other available bands—sometimes referred to as "Super Wi-Fi," as it utilizes Wi-Fi like protocols on TV spectrum. This allows the district to connect very remote households beyond the range of standard Wi-Fi technology. The network is owned and operated by RiverStreet Networks under a contract with the school district. The Friday Institute provided funding for equipment as well as expertise for the network design, implementation, and monitoring.

Motivations & Background

The Friday Institute began discussions with the school district about a TVWS solution for remote households before the pandemic, in 2018. At the time, they were unable to secure sufficient funding to pursue a pilot to connect student homes. NC's coastal area and Outer Banks region has struggled to obtain reliable internet connectivity for many years, due to a lack of viable provider options (slow DSL is the primary option), affordability barriers for households, and the challenge of reaching rural homes spread out across a large geographic area. Much of Hyde County is considered low-income, with over 90 percent of students taking part in the free or reduced-cost lunch program.

The county does have a relative abundance of available TVWS spectrum. Because the availability of contiguous TVWS channels is typically greater in rural areas, a TVWS wireless component represented a viable solution for the Hyde County network. The Friday Institute determined that Hyde County and several surrounding counties were the ideal locations for a TVWS pilot based on available spectrum.

In December 2020, the NC Department of Public Instruction (NCDPI) awarded the Friday Institute a $250,000 grant to research innovative wireless technologies that could provide students with home internet access. A portion of this funding has been dedicated to Hyde County for the TVWS network, as well as for Low Earth Orbit (LEO) satellite internet service on Ocracoke Island (population 973). The Friday Institute is also piloting LEO satellite and a Citizens Broadband Radio Service (CBRS) in three other NC counties.

Prior to this effort, Ray Zeisz, Senior Director at the Friday Institute, studied TVWS pilot programs at two southern Virginia school districts. Through this research, Zeisz developed a working partnership with RiverStreet Networks and 6Harmonics. RiverStreet acquired the original Hyde County local phone provider, and a small regional WISP. With RiverStreet being the only local wireless provider in a county with a population density of 7 people per square mile, Zeisz found it was the only long-term sustainable option.

After some successful tests using the contiguous TVWS channels available in the county, they decided to explore a model that would “seed” the market in the area by connecting students’ homes to TVWS, and ensure that a number of families would have fully-funded service and equipment for a year. RiverStreet would use these initial connections to bridge a broader TVWS and additional unlicensed wireless services in the area. RiverStreet and Hyde County schools worked together to identify families in need of broadband access and ideal locations for base stations for an initial pilot.

Technology

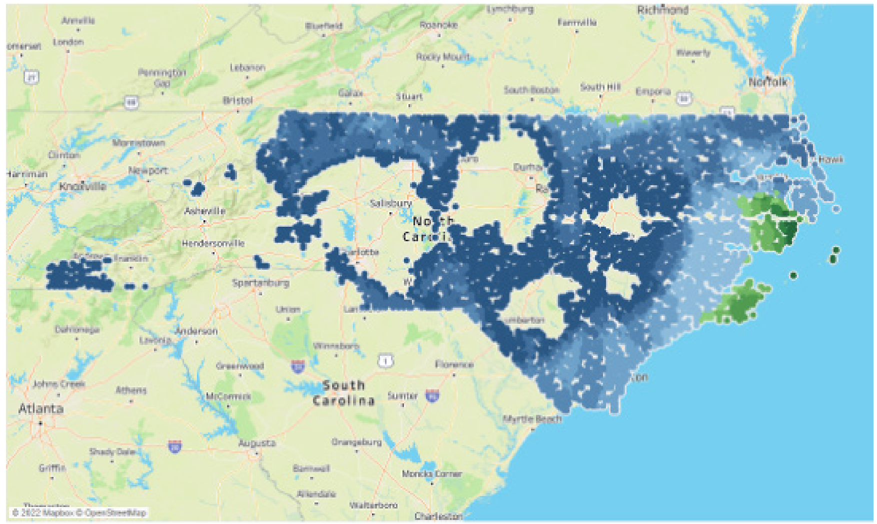
TVWS CPE installed near Engelhard, NC.
Source: RiverStreet Networks via Friday Institute

After conducting several tests, RiverStreet and the district decided to install four TVWS radios, known as Access Points (APs), that are each able to support at least 10 households with Customer Premise Equipment (CPE) connections (CPE pictured above). RiverStreet is using a single water tower to locate all four APs. Each AP is oriented to provide the most optimum coverage area for signal transmission.

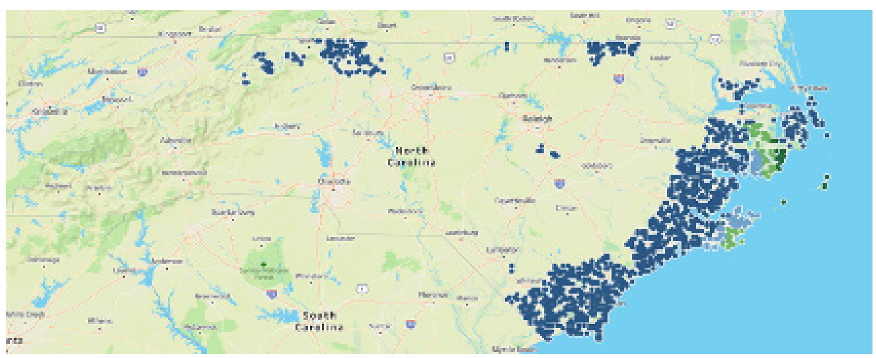
This initial service area has access to 15 available TVWS channels, each of which is 6 MHz in bandwidth. Each base station is currently using three contiguous channels, which is expected to increase to four channels after a testing period. This will create an effective bandwidth of 24 MHz with the four bonded channels. As noted, Hyde County and other coastal areas have much more available contiguous TVWS spectrum, whereas areas near larger cities have few (if any) available TV spectrum. The map below shows the total available TVWS spectrum in North Carolina. The green areas have the most available spectrum in total. Areas with no color have no spectrum available.

The second map shows the locations in North Carolina with four contiguous TVWS channels. As you can see, there are fewer places in the state that can support the full capability of the 6Harmonics radios. While the APs will work anywhere in the state covered in the first map, they will operate at lower throughput.

Each base station can reliably send a signal up to five miles and deliver approximately 80 Mbps of near-symmetrical capacity per base station. This translates to user speeds within the range of 7/3 Mbps up to 45/25 Mbps, depending on the distance from the TVWS radio and number of simultaneous connections. The median user speed is roughly 20 Mbps symmetrical. The network has seen low overall latency from household speed tests – around 35 milliseconds on average. Each household connects to the base station via an external antenna (CPE) that is connected to an indoor Wi-Fi router. Students can connect through district-provided Chromebooks, which are equipped with filtering and security measures that are CIPA compliant. By January 2022, 30 student/educator households were connected to the new network, using the TVWS equipment. For many of these previously unserved households, connecting to this network provided them with internet at home for the very first time.



TVWS Spectrum Availability in North Carolina
(dark blue lowest amount of available spectrum; dark green highest).
Source: North Carolina State University, Friday Institute



Areas with four Contiguous TVWS channels.
Source: North Carolina State University, Friday Institute

Impact

This small TVWS deployment is having a positive impact on a number of student households, some of which have never had an internet connection at home. Given the necessity for internet connectivity for homework, remote learning and other important purposes, such as healthcare and employment, this deployment is having a lasting impact on these families. Importantly, this initial stage is seeding a larger buildout that will include a variety of wireless technologies, most likely including more TVWS, to reach rural and unconnected families in the county.

Cost & Funding

The cost of this initial phase of the build out was approximately $60,000. RiverStreet is tasked with maintenance, technical support, and growing the network further beyond the "seeding" stage. The operating costs of the TVWS portion of the network is relatively minimal at this point. The radios and household CPEs might require maintenance occasionally, but at this initial scale, the labor is nominal. Recurring expenses, such as electricity to each radio, is equivalent to the cost of lighting a 60-watt light bulb.

Student households are provided a no-cost internet connection for the first 12 months of the pilot program. After the initial 12 months, the subscription costs will transfer to households that choose to maintain the service. The broadband subscription costs after the 12-month pilot period ends will be minimal—particularly for households that qualify for ACP—when RiverStreet finalizes those subscription cost-tier details.

Challenges

Zeisz and the Friday Institute are working to produce more rigorous quantitative analysis of the TVWS network, as well as the CBRS and LEO initiatives. Zeisz recently added a PhD student in wireless engineering to expand their analytic capabilities. Additionally, they have faced challenges in deciding whether it is most effective to buy more powerful CPEs (with higher gain antennas) to connect to existing APs, or whether installing additional APs would be more beneficial. Zeisz explained it is a decision RiverStreet will need to make based on density metrics and the incremental cost of additional towers and backhaul.

Going Forward

RiverStreet and the Friday Institute see promise in TVWS. It can be a viable option for WISPs that want to augment and extend the reach of existing towers that are using higher frequency bands, such as 900MHz. TVWS has the ability to get through foliage and provide incremental revenue to the WISPs with minimal new infrastructure investment. They do not expect to see a TVWS-only tower—it is more likely that TVWS would be the top antenna, and as you go down the tower, other higher frequency bands would be used. Since the expensive part is the tower and the backhaul, adding a couple of TVWS radios on top of an existing tower could be helpful in connecting some hard-to-reach students, but it would not be the go-to technology for nearby students.

Key Takeaways & Success Factors

- When vacant TV channel spectrum is available, TVWS technology can be effective to extend basic internet access to remote homes up to five miles from an access point, but is best used in combination with other wireless technologies, such as Wi-Fi or CBRS.
- Utilizing unused and unlicensed TVWS spectrum has the potential to provide a low-cost wireless connectivity solution in otherwise hard to reach locations.
- Hyde County found that partnering with a commercial WISP can both outsource risk and the need for technical expertise, while also qualifying for certain subsidy programs (currently ECF and ACP) that focus on paying commercial ISPs for monthly subscriptions.
- Achieving 30 household installs under this program would not have been possible without the 12-month subsidy to cover the cost of the internet connection.
- Building the first 12 months cost of internet service to the homes into the Capex was a key and critical ingredient in this project.

CBRS NETWORKS: PRIVATE LTE ON SHARED SPECTRUM

Fresno Unified School District, "Connect2Learn", Fresno, CA
Network Lead: Phillip Neufeld, Chief Information Officer

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
70,000	25,000 students (coverage)	3.5 GHZ (GAA)	30-80/5	$1.4M (phase 1)	$148,000	CARES Act ECF

Unique Qualities

Under the dedicated direction of the district's Executive Officer for Information Technology, Philip Neufeld, Fresno Unified School District (FUSD) has constructed a robust private LTE network using free access to CBRS spectrum to connect students throughout the district. FUSD carefully considered numerous variables to determine the design of the network and the technology used. Although FUSD originally hoped to deploy a mesh Wi-Fi and LTE solution (similar to the San Jose and Council Bluffs networks profiled here), the city's refusal to partner and grant access to street infrastructure, as well as the absence of modern light poles, pushed them to a more wide-area solution primarily mounting access points (APs) on school buildings ("schools-as-towers") to deploy private LTE at higher power. Notably, the district designed their own application to track network performance, and Neufeld's skilled team undertook rigorous testing and analysis to ensure the most robust network design possible. Following a relatively quick timeline, phase one has been completed and spans 24 school neighborhoods, and phase two will fill in coverage gaps and further expand coverage to the entire student population.

Motivations & Background

FUSD is California's third largest school district with about 70,000 students. FUSD determined that for educational purposes, every student must have access (both at school and home) to a top-tier digital learning experience that equips them with the necessary skills and knowledge for the future. In 2019, Neufeld and the district became painfully aware of the gap in broadband internet service at home for students, particularly as classrooms began relying more heavily on digital content and Windows laptops. Estimates from the California Public Utilities Commission showed that less than 5,000 households were under-connected and FCC data (since discredited) suggested less than 4,000 households were under-connected in a county with around 1,000,000 residents. But Neufeld experienced a different reality through interactions with students, educators, the local housing authority, and analysis with a self-designed digital application.

With the onset of the COVID-19 pandemic and the transition to remote learning in 2020, FUSD accelerated their planning process. Before deciding that CBRS technology was the best use case for the district, FUSD considered both Educational Broadband Service (EBS) spectrum (2.5 GHz) and meshed Wi-Fi solutions. They found that both Fresno County and Fresno State University had leased out all of the applicable EBS licenses in the area to cellular carriers (a local carrier that in turn leased the spectrum to T-Mobile, which is not actively using the spectrum).

FUSD also explored a meshed Wi-Fi solution and submitted a proposal to the city to mount Wi-Fi transmitters on city-owned street light poles, as the school districts in Council Bluffs and East Side San Jose had successfully done. However, the city did not move forward with the request. Fresno also participated in the Sprint One Million and T-Mobile 10 Million program for hotspots and distributes these hotspots as needed. That said, a major shortcoming in Fresno (as in many low-income or less densely populated communities) is that cellular signals aren't strong enough to support remote learning, particularly inside homes.

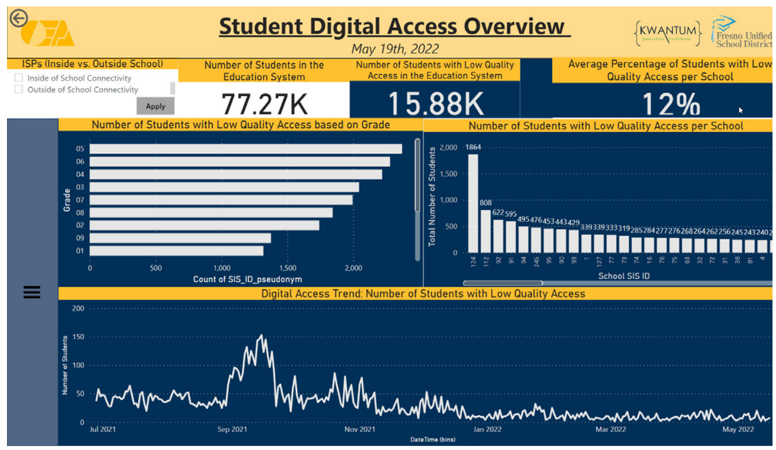
In late 2020, Neufeld and the project team agreed that CBRS technology offered the right balance between propagation and end-user speeds, taking into account the siting available for APs (school buildings, but not street furniture), topography (flat), and student population density (relatively low compared to high-density urban areas). In the fall of 2020, funding was secured with a two-stage RFP completed. In late January of 2021, the board awarded the buildout contract to Nokia and Netsync, based on a joint proposal. By the summer of 2021, 10 of the 15 radio sites (all mounted on school buildings) were completed. Notably, FUSD went through the processes of research, funding, RFP, board award, design, and buildout all within nine months due to the **ESSER funding** time constraint. The remaining five schools-as-towers required some structural modifications and all 15 sites were completed and live by October 2021, with the pilot ongoing until early 2022. During this initial pilot phase, the district distributed a small set of customer premise equipment (CPE) to student households. The design and deployment for phase two will begin at the end of summer 2022.

Technology

FUSD's private LTE network uses CBRS wireless technology from Nokia. The APs transmit on the free-to-use general authorized access (GAA) portion (80 megahertz) of the CBRS band. As noted, the vast majority of the Nokia base stations are mounted on school buildings (schools-as-towers). Some monopoles will be installed in phase two to remedy coverage gaps where school infrastructure is not available and where elementary school sites do not provide high enough assets for adequate line-of-sight coverage. The district has a very comprehensive understanding of the network's existing coverage, the existing need, and the capabilities of the connection across each deployment sector. In addition to analysis from the vendors, Neufeld and his team conducted several "drive analysis" tests where they physically drove Cradlepoint CPEs around in a vehicle to get an on-the-ground understanding of the coverage in each sector.

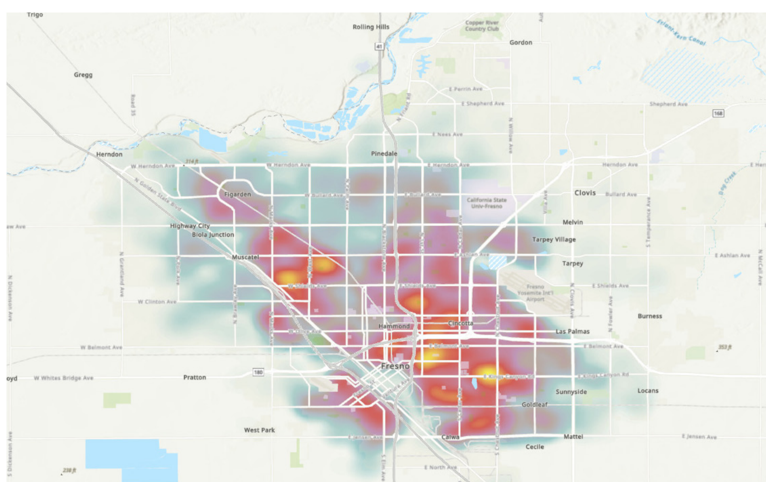
The district's fiber ring is connected to the internet through the nonprofit Corporation for Education Network Initiatives in California (CENIC), which provides two 40 gigabyte (GB) symmetrical connections. The CBRS network uses this for backhaul for the WAN and its internet connection, although the WAN is in the process of being moved to a leased dark fiber option. Currently 11 of the school sites are connected to the core fiber ring, with an additional 62 to be added in phase two. The core fiber ring provides a capacity of 40 GB, which will increase to 100 GB by 2023 to support the district's continued expansion.

Each student household receives either an AC-powered Cradlepoint CPE (R500) that is required to be plugged in for power, or a Kajeet Enseego model that is portable (MiFi 8000) and does not require an AC power source to function. For the completed first phase, FUSD has distributed only the Cradlepoint CPEs, since early beta testing indicated they performed best, but it also plans to include the Enseego MiFi in phase two. Each CPE requires a configured SIM card that hat allows the CPEs to connect to the private LTE CBRS network. All of the CPEs are indoor devices and the district does not mount antennas on the exterior of households. The CPEs both receive the private LTE transmissions from the APs and serve as a router, rebroadcasting Wi-Fi to the Windows laptops that connect and authenticate through a school SSID. Neufeld and his team have considered antennas that adhere to household windows to increase the CPEs antenna gain, but external installations aren't feasible, given the labor capacity needed for that addition.



MyQol application's administrator dashboard displaying the number of students accessing the network by grade, school, and total student access over a 6-month time period. **Source:** Fontana USD

The district designed their own MyQol application that collects measurement data from the students district-assigned laptops, such as upload and download speeds, latency, network usage/carrier, and the latitude and longitude of devices (see Dashboard screenshot above). The app has become a useful tool for both day-to-day monitoring, and planning for phase two, and will certainly be beneficial for troubleshooting coverage gaps in the future. It also allows Neufeld and his team to derive insights about engagement, outcomes, and measures of equity.



This 'heat map' shows the geographic distribution of downstream throughput on the FUSD network, which the district monitors. **Source:** Fresno Unified School District.

Impact

Upon completion of phase two, the network will consist of 45 APs—schools-as-towers and on monopoles where height is required—with the capacity to support 18,000 concurrent users across more than 65 school attendance areas. The district is able to monitor types of student activity on the network using the MyQol application. The app's Hybrid Engagement Dashboard shows the number of students connected, from which schools and grade levels these students are connecting, and other useful metrics, such as average days digitally active.

Cost & Funding

The total budget for phase one was $1.4 million, the bulk of which was used for equipment and installation. The cost for the Nokia Evolved Packet Core (EPC), 15 APs, and 45 antennas and RF jumpers totaled approximately $781,000. CPE equipment totaled approximately $326,000 for Cradlepoint R500, and SIM cards CPEs will be purchased using ECF funding. In total, the equipment components cost approximately $962,000, and installation costs were just under $295,000.

FUSD estimates that annual maintenance costs will average about $148,000 for the phase one area over the next five years. Some unexpected costs for engineering, electricians, and inspectors came to the fore, but ultimately the district didn't exceed their planned budget because of the deep discount they received. The fiber backhaul will cost an estimated $2,000 annually, due to the cost allocation rules imposed by E-Rate. The entirety of the funding for phase one was derived from CARES Act funding allocated to the district and approved by the school board.

Phase two will cost an estimated $6.3 million for 30 additional APs, an additional LTE core to split the network's overall traffic, and 45 antennas and radio frequency (RF) jumpers. FUSD is engaging with the local WISP O&M to deploy phase two. Neufeld explained they are well-versed in radio frequency design, tower climbs, and other important mechanics of a network build-out. The cost also includes an additional 10,000 CPE units. Additional costs for phase two come from the anticipated need for monopole towers in sectors where tall enough school infrastructure is not available. FUSD estimates the additional maintenance costs for phase two—which includes Nokia support, software updates, and field maintenance—will be roughly $295,000. In sum, FUSD forecasts that the total buildout costs will be approximately $7.7 million, and annual operating cost will average around $443,000, including the purchase of additional CPEs.

Challenges

In the construction of the first phase, due to the use of schools-as-towers, Neufeld and his team encountered a few architectural hurdles that required constructing some modifications to standard rooftop mounts. The completion of the first pilot also revealed the importance of height of the vertical assets available for mounting radios for ensuring reliable propagation, as well as the strategic importance of the quality and placement of CPEs at student households in each specific sector to achieve a strong connection.

Through the network design process and ongoing testing of the deployment in phase one, FUSD learned how different types of CPE devices can vary across performance metrics, such as throughput, power rating, and antenna gain. Based on the network design and triangulation of radios and antennas in phase two, they plan to use the portable Kajeet Enseego Mi-Fi 8000 in portions of the second phase deployment, particularly for students who move around more often. Kajeet hotspots are notably durable, as they are designed to protect against drops and the normal wear-and-tear of traveling with the equipment. Neufeld noted this feature implicates equity, since very low-income students move more frequently on average.

The FCC initially denied the district's application for ECF reimbursement for the cost of the other Cradlepoint CPEs due to a misunderstanding that the CPEs were part of the infrastructure of an LTE buildout. However, CPEs are routers that are typically required for cable or any commercial home internet service. FUSD has modified its application, and through numerous conversations with USAC, the application for 2,000 CPEs was approved.

Going Forward

Planning for phase two accelerated when the district's board approved the budget in March 2022. Reflecting on lessons from phase one, they learned that the height of radio nodes is critical, but not all schools or other public buildings can support heavy extensions without structural changes. Where school infrastructure isn't sufficiently tall for phase two, FUSD would like to collaborate with the city and county to use existing infrastructure and construct monopoles where necessary. They are also mindful to test actual reception before moving forward with an RF design in each sector, and not rely solely on the theoretical RF design. FUSD found in phase one that the actual RF propagation when deployed was much better than theoretically anticipated, a welcome surprise. Lastly, they hope to collaborate with State Center Community College District to further extend the reach of the network and create a more robust long-term connectivity solution for more students.

Key Takeaways & Success Factors

- Although a mesh Wi-Fi network would have provided far greater capacity and potentially lower costs, the inability to access city street poles (for Wi-Fi) pushed the cost-benefit analysis to settle on private LTE that relies on the GAA portion of the CBRS band.
- FUSD quickly learned that deploying a network with different use cases and thus different CPE solutions (e.g. fixed and mobile CPE units) is a challenge to manage as an anchor institution without a partnership with a WISP or other private entity that provides IT assistance.
- FUSD is now working with trusted community groups to train them to assist with basic troubleshooting and setting up student CPEs in the home.

Neufeld strongly believes that connectivity is a multifaceted issue that requires different and varied responses to improve what he calls the community internet ecosystem.

Fort Worth Independent School District (FWISD), Fort Worth, TX

Network Lead: Marlon Shears, Chief Information Officer

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
76,858	25% of Households in need	CBRS (GAA)	25/5 (average minimum)	Approx. $5M	$180,000	CARES ECF

Unique Qualities

District CIO Marlon Shears has spearheaded the CBRS wireless solution at FWISD after a significant amount of planning, testing, and discussions with experts and neighboring Texas districts with existing wireless networks, such as Castleberry ISD. Shears previously helped Dallas ISD begin planning that district's CBRS wireless network, so he brings a level of first-hand expertise that many districts do not have on staff. The district's initial pilot buildout went live in May 2021, and construction for the remainder of the network began in spring 2022.

Motivations & Background

FWISD is a large district with a total enrollment of nearly 77,000 K-12 students. Shears is crafting the network to provide coverage to student households identified as lacking an adequate home broadband connection and, secondarily, to cover as many student households in the district as possible. Undergirding both of these priorities, FWISD is initially targeting high-density areas to reach as many students as possible per access point (AP). In the early stages, FWISD plans to leverage commercial fixed broadband ISPs or mobile carrier hotspots to fill in some expected coverage gaps.

Technology

The network uses CBRS technology and Cradlepoint equipment for both base station transmitters and customer premise equipment (CPEs). Shears said FWISD considered a meshed Wi-Fi solution, but noted that the less densely-populated profile of the Fort Worth area made that a less feasible and cost-effective option for achieving optimal coverage and adequate end-user throughput. Because meshed Wi-Fi requires a far larger number of APs to cover a given area, it is most optimal when districts have access to widespread siting, such as street light poles and traffic signals, that also provide power for the equipment. That said, Shears explained that the monopoles deployed for phase one, which are currently mobile (mounted on trailers), have the capability to support 5G small cells if the district decides that the far higher capacity needed for 5G applications justifies the costs of a more dense buildout in the future.

The mobile monopoles facilitated the preliminary testing of the pilot network, but, as noted above, they will eventually be permanently installed. The remainder of the network will be deployed using schools-as-towers (similar to the architecture of the Fresno USD network profiled here), with an expected 18-to-20 more base station radios needed to provide coverage to the remaining student households in need. FWISD initially began by distributing indoor CPEs to student households and providing guidance for setting them up in the home (i.e., next to a window). Now the district is moving towards customizing each household deployment and potentially installing external antennas to improve reception where needed and feasible. The network's core comes from Airspan. The fiber backhaul is provided entirely by the district, which must allocate the cost attributable to the CBRS network use off campus so that there is no E-Rate discount. The district began moving to 10 GB optical capacity from their previous 1 GB fiber connections, and they expect to install additional dedicated fiber runs where needed.

Impact

The network has the capacity to serve 60,000 unique connections. Shears projects that upon completion of the full deployment, roughly 50 percent of the student population will have coverage, or approximately 32,000 students. There will be over 50,000 students total in the coverage area. If student households that already have a connection decide to utilize the FWISD network, total connections could be closer to 75 percent of the student population. In the initial pilot phase, end user speeds averaged around 75/10 Mbps, although this is greatly dependent on each household's distance from a base station and the topography. Shears noted that the average minimum throughput is roughly 25/5 Mbps, but in some challenging cases – such as where households were a mile or farther from an AP – speeds could drop to about 10/3 Mbps. For these households, Shears and the district are exploring previously noted interventions, such as installing external, higher-gain antennas at students' homes.

Cost & Funding

The entire buildout is estimated to cost approximately $5 million. The first phase will cost approximately $3 million, representing the majority of the overall budget, due to the cost of the LTE core, server, and basic architectural design work, which sits at roughly $1 million. The core is a large one-time cost that will support the entire network (and permit up to 60,000 simultaneous connections). Additionally, the first phase incurred a higher cost for the initial four base stations because they are deployed on monopoles, which are roughly $250,000 each. The second phase will utilize school infrastructure (schools-as-towers) to locate 18 to 20 more APs at a cost of approximately $2 million, which is significantly less expensive per site than in phase one. FWISD estimates ongoing operating costs will remain around $180,000 annually, the entirety going to BearCom, a private firm, for ongoing maintenance and servicing.

Challenges & Going Forward

The district has worked through expected challenges, such as variance in end user speeds due to distance and topography, and is addressing other connectivity challenges on a case-by-case basis. They've also begun considering customized deployments for households, installing external antennas where necessary, as well as other options.

FWISD received FCC approval to install the four initial phase one monopoles, which were mobile units, in permanent locations. The second phase began in April 2022, which will primarily consist of mounting the phase two base station radios at school buildings, as well as some architectural design and running power to equipment.

Key Takeaways & Success Factors

- Fort Worth ISD exemplifies what can be achieved with a knowledgeable and motivated technical leader who networks with other leaders in the field and implements known best practices.
- FWISD initially considered a dense mesh Wi-Fi deployment, but concluded that the geographic density of student households with the greatest need, as well as the availability of street poles or other more ubiquitous siting options, made private LTE using free CBRS spectrum and higher siting for base stations the best option.
- FWISD employed mobile monopoles to expedite a private LTE pilot deployment, verifying coverage areas, and is now moving to permanent installation, along with a larger number of more economic schools-as-towers installations.
- The district has nimbly adapted to the evolution of CBRS technology and the challenges that have risen

Castleberry Independent School District (CISD), River Oaks, TX

Network Lead: Jacob Bowser, Director of Technology Operations

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
3,700	750 students (20% coverage)	CBRS (GAA)	10/10 up to 200/15	$660,000	$118,000	ECF

Unique Qualities

Castleberry ISD (CISD) was an early adopter of CBRS technology as a school wireless connectivity solution. Its network has been viewed as a model by the district's much larger neighbor, Fort Worth ISD. CISD's network has a large impact relative to its size, covering 20 percent of student households with only three cell towers. Jacob Bowser, Director of Technology and Operations, led the research and design efforts for this network, and maintains it nearly on his own. CISD exemplifies a robust networking solution for students, but also highlights the importance of a strong technical lead in designing and implementing a solution in a small district.

Motivations & Background

By January of 2017, CISD was becoming more aware of the "homework gap" afflicting a large portion of the district's students. About 85 percent of the families in the district are considered economically disadvantaged. After conducting surveys and gathering student data, they found students without a reliable home internet connection largely mirrored the 85 percent share of families that are economically disadvantaged.

Bowser and CISD began exploring vendors and their connectivity solutions for students at home. They eventually decided on a private LTE solution from **M&A Technology**, a private firm providing end-to-end network services, utilizing free spectrum in the General Authorized Access (GAA) portion of the newly-available CBRS band. Compared to other connectivity options the district explored (e.g., mobile hotspot subscriptions), Bowser explained that M&A provided a solution with the best potential for adequately connecting students, while still having a relatively low cost of total ownership. CISD's Board of Education unanimously approved the proposed network. Bowser also noted that because most of the district's students live in fairly densely-populated neighborhoods, the district initially considered a meshed Wi-Fi or point-to-multipoint Wi-Fi option, but abandoned those options when a suitable vendor could not be identified. Moreover, because Bowser planned to manage all aspects of this network himself, a private LTE solution with few base station sites seemed more practical than a more equipment-heavy, densely-deployed option like mesh Wi-Fi.

Through the spring and summer of 2017, CISD, M&A, and their partner ZTE (a wireless network equipment manufacturer) began designing a private LTE network as a predecessor to the CBRS network, since, at that time, the FCC had yet to finalize CBRS rules or authorize deployments.[2] They conducted a radio frequency survey and employed computer simulations to visualize the most efficient network design (i.e., link budget), eventually deciding that three strategically placed towers would serve all of CISD's enrolled students. Thereafter CISD and its private sector partners entered planning, permitting, and construction phases, which were completed by March 2018.

They began testing the first phase of the network (the first tower completed) that spring, and entered a pilot phase during the summer of 2018. In the fall of 2018, CISD sent out interest surveys to CISD families and initially had around 100 families sign up, with many more eventually joining. Families that agreed to the responsible use policy were able to check out indoor customer premise equipment (CPEs) from school for their homes. The second tower was completed by January 2019 and went live that March, followed by the third tower in February 2020, which went live just as the pandemic shutdowns began in March 2020.

Technology

CISD's wireless network currently uses private LTE technology on the free GAA portion of the CBRS band of spectrum. As noted above, three strategically placed towers were sufficient to ensure coverage for all CISD student households at Castleberry Elementary, Joy James Elementary, and A.V. Cato Elementary. Bowser explained that there were not many vertical assets available in the strategic locations needed to maximize coverage, which necessitated the placement of monopoles to mount the base stations–access points (APs)– high enough above ground. This also required seeking special use permits and conducting a geotechnical survey to ensure the sites could support a tower. Going forward, the network can be supplemented with additional rooftop APs to improve coverage and speeds.

CISD uses Nokia equipment end-to-end and connects to students' homes via primarily indoor CPEs that are distributed by the individual schools. Bowser noted that the indoor CPE antennas in students' homes have about half of the antenna gain, or signal strength, compared to externally mounted antennas. External antennas require installation, however, which not only increases the cost, but is also often prohibited at many residences, such as rental homes and apartments. Bowser also noted that the FCC's new rules aimed at facilitating the use of external antennas in multi-dwelling units were released in 2020, after CISD had already planned and built out most of the network. The majority of the CPEs are indoor and do not require installation, but they have begun installing some outdoor units for houses that would benefit most from the higher gain antennas.

CISD sources fiber backhaul for the LTE network from commercial ISPs. They have access to Texas' regional Education Service Center 11 (ESC 11) fiber—one of 20 ESCs created by the state for school districts and charter schools that also provides technical assistance as well as professional development and management of schools' educational programs. That said, ESC 11 fiber is mainly funded through E-Rate. Bowser explained that it would be more trouble than its

[2] The network began as a private LTE network (FCC Part 90) which CBRS rules (FCC Part 96) would eventually supersede. CBRS rules had not been finalized or implemented at scale when the district started building the network in 2017.

worth to try and effectively cost-allocate to use the ESC 11 fiber for the CBRS network backhaul. “We’re better off paying out of pocket for the [fiber] backhaul,” Bowser said.

Impact

CISD’s network is serving around 20 percent of student households in a district where 86 percent of student households were receiving free or reduced lunch for the 2020-21 school. CISD confirmed through surveys that these lower-income households were, as expected, mostly lacking a reliable broadband internet connection. Bowser explained that providing free, reliable internet to around 750 student homes is incredibly impactful for educational outcomes, and that having a sustainable wireless network that has been operating for nearly two years has provided a necessary foundation for expansion and further impact.

Cost & Funding

The capital costs for CISD’s network were primarily attributable to the three towers for APs, a reality for localities without access to viable vertical assets. The CBRS towers cost approximately $220,000 each, totaling about $660,000 for the existing network. This cost includes the Nokia APs and related wiring. The CPEs distributed to student households cost between $200 to $300, depending on whether they are indoor or outdoor units. As noted, CISD leases some fiber backhaul from a commercial ISP, which costs around $1,000 per month. Operational costs are estimated at around $118,000 annually, which includes the leased fiber, as well as the permitting fees for one of the towers.

CISD used local district funds to build the network. Bowser noted that they weren’t able to take advantage of any other types of funding during that time period, which predated COVID-19 relief funding. The district does receive category one and category two E-Rate funding at an 85 percent refund rate, but they do not cost allocate or rely on E-Rate funded backhaul for the external CBRS network. Bowser explained that it was less expensive this way, given the majority of their fiber backhaul comes from ESC 11. CISD is receiving some ECF funding for some student computers, but the district has been unable to apply for reimbursement for the LTE network infrastructure or backhaul costs, even though the anticipated long-term costs are less than purchasing commercial monthly internet subscriptions.

Challenges

Beyond the expected networking challenges, such as weak signals for some households due to indoor CPE placement, Bowser explained that one of the main difficulties is securing outside funding to expand the network to cover more students in need. He noted that the rules attached to ECF constrain his options for expanding connectivity to students, and also his options for connecting the community. For example, he is considering using the CBRS network as backhaul for community Wi-Fi hotspots through a collaboration with the local library (more details on this below), but ECF funding restricts their ability to use that network connection for the community. As a result, he is instead considering subsidizing incumbent ISP connections to student homes using ECF funding, while it lasts, since that is a clearly authorized option for using those federal funds.

Going Forward

CISD and Bowser have been exploring ways to expand the network to more low-income student households. Given that Wi-Fi point-to-multipoint technology is much more developed at this stage—and new Wi-Fi 6E technology is about to radically boost the capacity of Wi-Fi connections with access to 6 GHz spectrum—Bowser is considering adding this to the network. The district has also been collaborating with the Texas Education Agency's (TEA) Connect Texas Program to reach agreements with local ISPs for subsidized connections at students' homes. Bowser explained that TEA would cover a portion of each household subscription, and CISD would pay the remainder, likely around $20 monthly. As of October 2021, Bowser was trying to get ECF funding to cover that portion of the subscription cost, but also made clear that CISD would pay that out of pocket if they didn't get ECF funding.

CISD is also collaborating with local libraries and with the nonprofit Gigabit Libraries Network to deploy pop-up library cabinets that also contain Wi-Fi hotspots for community use. Bowser is exploring backhauling these hotspots using the existing CBRS infrastructure.

Key Takeaways & Success Factors

- Rely on the expertise of your integrators and contractors. Bowser began implementing the network before private network integrators had any experience with the new CBRS technology. Now integrators have experience and know best practices to offer valuable expertise. Even though it is still possible to build a CBRS network DIY-style, as Castleberry did, school districts—especially smaller ones—will save time by contracting with an experienced integrator.
- Know the topography of your community. If possible, early on a GIS team or specialist should provide rough coverage estimates by using viewshed calculation tools. This in turn informs the use of RF (radio frequency) planning tools, such as the **Google Network Planner tool**.
- It's important to know which students and geographies need to be covered and which do not, as this helps in locating access points and devising other connectivity solutions to fill gaps. It is also important to target the advertising for your private LTE network toward those families who will be covered.
- Bring the community on board. CISD initially received pushback from some prominent members of the community who believed that low-income families needed to "pull themselves up by their own bootstraps" and not rely on the school system for connectivity. The district used a series of public hearings, planning and zoning meetings, and City Council meetings to eventually forge a consensus focused on the needs of students and the benefit they and the schools would gain from the network. Bowser advises school officials to "be ready to fight for your project".
- Advertise as much as possible. A fast, robust wireless network does not boost educational outcomes if nobody knows about it. Bowser advises schools to send home flyers with every student and put up yard signs, electronic signs, billboards, or whatever is affordable. Remove as many barriers to entry as possible. Bowser also suggests the importance of making paper applications available to families who have no connectivity, especially since some don't even have smartphones.

Fontana Unified School District (FUSD) Fontana, CA

Network Leads: Randy Bassett, former Superintendent
Oscar Dueñes, Chief Information Technology and Innovation Officer

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
36,160	Coverage for 4,000 students	CBRS (GAA)	40-80/8-16	$32.5M	TBD	(none)

Unique Qualities

Fontana Unified School District (FUSD) has partnered with Crown Castle Fiber (CC Fiber), a network infrastructure provider, as the anchor tenant on a purpose-built CBRS network funded and constructed by CC Fiber. FUSD's model is unusual: The district will not own the network, nor pay monthly subscription fees. Instead, the district has contracted to lease capacity that connects students in targeted areas directly to the school's network using private LTE operating on CBRS spectrum. CC Fiber currently owns and operates the network and has covered the majority of the build-out costs for the needed fiber infrastructure, with the expectation that they will get more tenants on the network in the future. As of July 2022, Fontana USD was designing a request for proposal process to bring in a new owner and operator to take the place of Crown Castle.

Motivations & Background

The district is in a predominantly low-income community where roughly 85 percent of the student population qualifies for the federal free or reduced lunch program. It's considered a suburban area, but most of the homes are quite spread out from the central part of Fontana, making fixed wireline connections (e.g., cable) more costly and less profitable to private commercial ISPs. Mobile broadband coverage in the area is spotty, with different carriers having better or worse coverage and/or signal strength indoors depending on the area. Fontana explored a mobile hotspot solution from AT&T in 2019, but when AT&T was unable to disclose how many of the announced 1,000 cell towers planned for expansion across CA would eventually be located in Fontana, or on what timeframe, they decided it wasn't a reliable option.

FUSD built an extensive fiber backbone network connecting all of the district's schools years ago. The district currently has fiber at 48 locations. In the years prior to the pandemic shutdowns, FUSD was already exploring options to extend connectivity to students at home. Former Superintendent and Chief Technology Officer Randy Bassett explained that he approached an incumbent ISP prior to the pandemic about the timeline for potentially extending their network to students in the district. Today, spurred in part by the availability of free access to CBRS spectrum, Bassett and CC Fiber have forged an unusual partnership, based on an anchor-tenant model, that he says promises to connect students in need with a more reliably robust and financially sustainable wireless network compared to relying on the purchase of monthly cellular subscriptions.

Bassett makes the point that because FUSD has no desire to manage a network, an arrangement with a service provider makes operational sense. Bassett also views the infrastructure being built for the network (vertical assets/poles and running backhaul to existing poles) as an investment that can be leased for 5G deployments to mobile carriers that will further facilitate technological growth and improved connectivity in the community.

Technology

The off-campus network is using CBRS technology to reach students' homes throughout the district. Homes are generally far from Fontana's city center, in what is considered an exurban rather than rural area with relatively low density. Therefore, CBRS's 3.6 GHz propagation and bandwidth capacity are a good option for FUSD.

As of spring 2022, FUSD concluded the first phase of testing a limited deployment of 40 base stations that offer coverage to about 4,000 students. It estimated that a total of 340 access points are needed to cover the district in its entirety. To avoid violating E-Rate rules, or cost allocating and thereby reducing its E-Rate funding, FUSD incurs additional costs to run all off-campus CBRS connections on 20 GBs of leased CC Fiber using separate switches and equipment. They also duplicate all connections and filtering to ensure they are not using E-Rate funds for the external CBRS network.

During the pilot period, CC Fiber tested different customer premise equipment (CPEs) to determine which devices ensure the best end-user speeds and reliability. FUSD distributes PCs to students, who connect to the school-issued CPEs, which in turn route the connections to the district's secure network. The access points (APs) for the CBRS network are being located on city-owned poles, and they anticipate building some additional monopole infrastructure as they expand the network beyond the testing phase.

During the 2021-22 school year, FUSD used mobile carrier hotspots to connect students in the interim. Bassett explained that the coverage is spotty and the connections are often not robust enough for remote learning due to weak signal strength. FUSD pays mobile carriers roughly $30 per month on average to ensure students have an appropriate amount of data for their coursework, an arrangement that is substantially more expensive than the CBRS network will be on a per student/connection basis.

Impact

The network remains in the first phase of the buildout, but as the ownership transition happens after the RFP process, Fontana USD predicts the new entity will conduct some assesments before finalizing the remainder of the buildout. The current active deployment consists of 40 APs and serves about 4,000 student connections. Bassett and Dueñes note that they have experienced very little interference and the network has not experienced any major technical roadblocks.

Cost & Funding

The district's overall five-year cost for use of the network that will include a total of roughly 360 APs and cover the entire district is estimated at approximately $32.5 million. This works out to approximately $14 per month for each student for the first 5 years. The district will pay half that amount ($7/month) after the initial period, since at that point the original buildout costs will be amortized. As noted, since the network is privately owned and operated, CC Fiber covered the total build-out cost, taking on more risk, with the expectation that they will get a substantial return on investment when the company acquires more network tenets in addition to FUSD.

Bassett explained that the district decided that leasing capacity as an anchor tenant on the CBRS network would be more cost-effective in the long run than purchasing monthly subscriptions from mobile carriers. Bassett and CC Fiber are confident that the CBRS network will prove viable in the long term, assuming the network provides the appropriate speeds and capacity to support necessary remote learning activities, such as interactive video streaming. The network also creates 5G-ready infrastructure that can be multi-purposed for Internet of Things (IoT) applications, providing valuable future assets for the district, as well as for future CC Fiber tenants, such as the City of Fontana, other businesses and even mobile carriers looking to enhance capacity on a targeted basis.

E-Rate rules are forcing the district to lease a separate, duplicative strand of fiber to carry the traffic from students and teachers back and forth to the school's E-Rate supported network. The FCC's rules increase the cost of extending the internet to students at home by forcing the district and CC Fiber to duplicate what has already been constructed (and not in use when students are out of school). Bassett noted that the E-Rate rules represent an additional and unnecessary expense on top of the cost the district already pays to lease fiber optic cable with 30 GB of capacity.

Challenges

An early challenge was the extended timeline for the pilot testing period that resulted from CC Fiber's decision to gather comprehensive data on the capabilities of multiple models to ensure the most robust CBRS network build. Because FUSD was just an anchor tenant on a shared network, CC Fiber took longer than initially expected to plan and deploy a more ambitious and marketable CBRS network that would attract additional tenants in the future. Unfortunately, COVID-19 brought further delays, and the current ownership transition is taking some additional time, but Dueñes is confident the network will be built expeditiously under the new arrangement.

During the planning and permit-seeking process for the build-out, FUSD also initially encountered hurdles with respect to locating network APs on city-owned infrastructure, primarily conditions and fees associated with installations on public light poles and buildings. The city initially asked the district to run their own electricity source to the APs, but they have since agreed that wiring parallel electrical sources is unnecessary. After discussing other design options, they have come to an agreement to use existing city-owned poles in almost all cases, which are connected to electricity, and their working relationship continues to be a productive one as they plan the remainder of the buildout.

Lastly, to avoid using fiber and equipment funded through E-Rate, the district and CC fiber have had to lease duplicative fiber strands and install separate switches to ensure they don't violate cost allocation rules. This hampered both the speed of the build-out and added unnecessary costs.

Going Forward

FUSD continues to work with CC Fiber to plan and deploy the remainder of the CBRS network. They estimate that it will require another 300 base stations (APs) to cover the remaining student population. FUSD believes after getting a new ownership agreement approved by the school board after the RFP concludes, the full buildout will be completed in roughly two years.

Beyond just connecting students, they have discussed co-locating Wi-Fi access points to the infrastructure being used for CBRS radios to offer Wi-Fi to the community, much as the school district mesh Wi-Fi networks do in Council Bluffs and San Jose (also profiled here). Bassett said the city has been hesitant to embrace that idea, but it is a feasible option that could help connect the community and support expansion to neighboring school districts.

Key Takeaways & Success Factors

- An anchor-tenant model can be a viable and cost-effective alternative to either building and owning a school network, or to partnering with the district's municipality or a local WISP.
- By sharing capacity on a privately built and operated CBRS network, Fontana USD substantially reduced upfront capital costs, risk and operating responsibility.
- Working with experienced private partners with a proven track record like Crown Castle (fiber infrastructure) helps ensure scaleable long-term solutions.

Val Verde Unified School District, CA

Network Lead: Matthew Penner, Director of Information and Instructional Technology

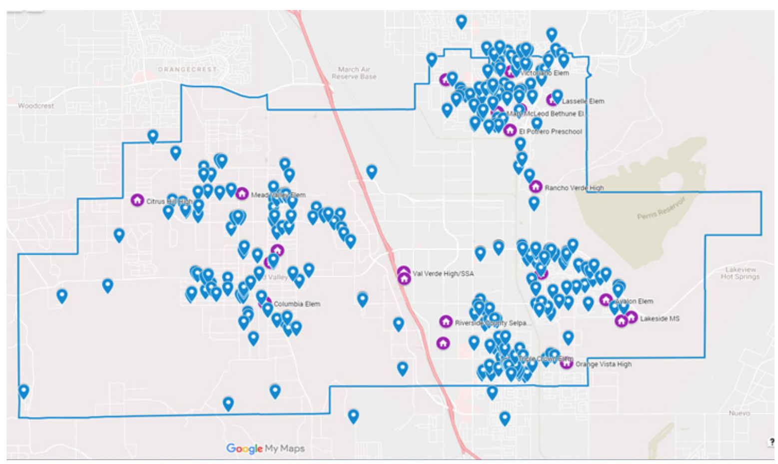
STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
20,000 students	1,400 student households (phase 1)	CBRS Wi-Fi	500-1,000 (planned download)	Approx. $5 M (phase 1)	5 year-opex included in capex (phase1)	(none)

Unique Qualities

Val Verde USD has partnered with GeoLinks, a well-established regional wireless ISP (WISP), to build an adaptable wireless network solution that has taken a best-fit approach that utilizes both Wi-Fi and CBRS technology to connect student households. The initial pilot phase began deployment in spring 2022 and will provide service to 1,400 student households with guaranteed service for five years. GeoLinks will also begin utilizing the network for commercial offerings to households as it expands the network's coverage area. Val Verde USD stands out for its partnership with a WISP building a dual-purpose network, its best-fit approach (utilizing multiple technologies), and its ultimate goal of connecting nearly all of its 16,000 student households.

Motivations & Background

Matt Penner, Director of Information and Instructional Technology, began exploring different wireless networking options about five years ago, when the district began providing Chromebooks to every student. At the time, the district didn't have funding to provide hotspots to students, so they trained educators to have students download all homework assignments at the end of class, allowing them to work offline when at home. While this sufficed for traditional school work, a lack of internet access vastly limited the rich educational engagement students benefit from when collaborating with other students, accessing content and dynamic learning resources online, and interacting with teachers and mentors outside the traditional classroom period.



An April 2020 map of K-12 students in Val Verde USD who had not logged in for remote learning one month after pandemic school shut-downs began in March 2020. **Source:** Val Verde USD

After concluding that this wasn't a sustainable long-term solution, Penner began probing different wireless connectivity options for students at home. Incumbent ISPs in the area at the time didn't have the bandwidth to deliver extra capacity to the school district.

All of the (Educational Broadband Service) EBS licenses in the district's coverage area are currently being leased. Also, the district's geographic density did not make meshed Wi-Fi a viable option in most areas.

Finally, afer CBRS spectrum and equipment became available in 2020, the district initiated a CBRS pilot at a high school located in a valley. That deployment provided a critical lesson on the importance of identifying geographical hindrances when considering CBRS, which generally requires line-of-sight, particularly at longer distances from the base station. Some areas received a robust signal, other areas no signal due to the contours of the valley. Deciding CBRS alone wasn't a scalable solution, they moved forward with a hybrid approach using CBRS and Wi-Fi in an anchor-tenant business model partnership with local WISP GeoLinks.

Technology

Using both CBRS and Wi-Fi technologies, the network will proceed with a best-fit approach for connecting households. The expectation is that Wi-Fi will be used for hilly areas and CBRS for flatter areas. Before officially entering into the partnership, GeoLinks compiled a robust study predicting user speeds, propagation, and other criteria to determine the most efficient network designs. GeoLinks holds CBRS Priority Access (PAL) licenses, and they will also utilize the free and shared 80 MHz (general authorized access) GAA portion of the CBRS band for that portion of the network. Like most WISPs, GeoLinks has relied heavily on the unlicensed 5 GHz band to deploy point-to-multipoint service to customers. While this is generically considered a Wi-Fi solution, it is a different, more targeted architecture that covers larger (and typically less densely populated) areas than the mesh Wi-Fi networks mounted on street light poles that have been deployed in more dense urban districts, such as Council Bluffs and San Jose (both profiled here).

Each student will have a CPE that includes an external antenna mounted to their home that connects to an indoor Wi-Fi router. Students are only able to connect to the network with their school-issued Chromebooks, which authenticate automatically to the school network. Penner noted that most of the wireless equipment (base stations) will be located on district infrastructure, primarily school buildings, but they also plan to coordinate with municipalities to use their infrastructure where necessary. The district is currently using an incumbent ISP to provide internet to their dark fiber that's leased from Crown Castle, but they plan to join the county office fiber network.

Impact

GeoLinks anticipates that ultimately the network can deliver very high-capacity throughput of 500 Mbps to 1 Gbps connections to each student household. For the first phase, the district plans to connect 1,400 student households. The 1,400 families can achieve these speeds through the physical installation of equipment at the house, such as a receiving antenna mounted on the roofline, much like a DirecTV dish, for example.

However, there will be a larger community impact. Households within the network's coverage area that do not have children in school can choose to pay for access to the service. Those households will have a variety of subscription cost tiers to choose from, based on the speed, data limits and hardware they choose. GeoLinks will offer the Wi-Fi based broadband offering to all residents within the district and in adjacent areas for $19 per month. GeoLinks will also offer two fixed broadband offerings throughout the district. Plan 1 will offer speeds of up to 1 Gbps for $79 per month and Plan 2 will offer speeds of up to 200 Mbps $49 per month. The commercial offering on the dual-purpose network will lower its overall cost per user.

Cost & Funding

The first phase will have a flat fixed cost of $5 million under a five-year contract with GeoLinks that includes the capital costs, maintenance, and five years of high-capacity service to the 1,400 student households. Val Verde USD will pay the entirety of this amount to GeoLinks. Penner noted that this fixed cost roughly equates to $20 a month per student over the course of five years for up to a gigabyte connection, a cost that could potentially come down going forward once the initial network infrastructure is in place.

Challenges & Going Forward

As described above, offering a robust yet affordable broadband connection to all students and a commercial service to neighboring residents has been a long term goal. During the school shutdowns due to COVID-19, this need became a critical priority. Fortunately, many of the state, federal and commercial funding opportunities provided a temporary solution by subsidizing mobile hotspots where possible. However, as COVID-19 pricing schemes for hotspots from commercial carriers phase out, Penner explained the importance of transitioning to connectivity solutions that ensure student access and long-term financial sustainability for school districts.

GeoLinks estimates the first phase will be completed in about one year, by Spring 2023. Looking beyond the first phase, the plan is to have 16,000 student homes covered, as well as a robust commercial WISP option for the community. The largest challenge continues to be funding—most federal and state programs, while temporarily providing short-term solutions such as hotspots, do not make allowances for district-funded fixed broadband networks. Projects like this will help establish the very real opportunities for long-term success when building an affordable and robust network for educational institutions.

Boulder Valley School District (BVSD), “ConnectME”, Boulder, CO

Network Lead: Andrew Moore, former BVSD Chief Information Office; Jim Hinsdale, President, LiveWire

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
31,000	1,000 student households	CBRS (GAA)	25 -100/ minimum 5	$264,000	TBD	ESSER EBB

Unique Qualities

Boulder Valley School District’s (BVSD) ConnectME network is the product of a public-private partnership with LiveWire, a small local wireless ISP (WISP). ConnectME takes an unusual and practical approach to make the network cost-effective by giving the WISP access to its schools-as-towers (for siting), CBRS base stations, and fiber backhaul. After trying but failing to receive a waiver from the FCC’s E-Rate rules to extend the school’s network to low-income students at home using unlicensed TV White Space spectrum (TVWS), BVSD settled on the new CBRS technology and this partnership with a local WISP as the most economical, effective, and impactful method to connect students in need across a challenging topography. This unique partnership enables BVSD to provide a free connection to students while LiveWire leverages school district infrastructure to extend its coverage in the community and provide an affordable commercial internet option, bolstering ISP competition in the process.

Motivations & Background

BVSD and Andrew Moore, the district’s Chief Technology Officer, have had a long journey to their goal of reliably providing internet to needy students at home. Moore explained that during the 2012-13 school year, he decided to extend the school’s E-Rate funded fiber to an adjacent public housing development where many students lacked broadband. Being new to both education and networking, Moore explained that it seemed like a simple and overwhelmingly logical option, given the network’s excess capacity outside of school hours. However, the FCC soon contacted the district, informing them they were in violation of E-Rate funding rules. In 2015, Moore submitted a waiver request to the FCC, requesting that any E-Rate funded equipment be allowed to service qualified students for educational purposes at home, including by leveraging the school’s fiber backhaul using wireless TVWS transmitters from school rooftop transmitters. The waiver request has been ignored by the FCC since its submission in 2015, despite active support by the Open Technology Institute (OTI) and the Schools Health Libraries Broadband (SHLB) coalition. Moore explained that this initial start-and-stop was the catalyst for finding an alternative way to connect students in need of broadband to the district’s network.

Over the next few years, Moore and the district explored various options. An initial obstacle was a restrictive state state law (SB 152) passed in 2005 that prohibits local communities from offering advanced telecommunications services to the general public, either on their own or with a partner. The law had a loophole, though: individual municipalities can hold voter referendums to opt out, an effort that started when voters in Fort Collins chose to opt out of the prohibition. In 2016, prior to Boulder's vote to opt out of SB 152 in 2017, Moore explored the use of a TVWS network to connect students at home. Although TVWS did offer a means to reach students living far from schools (where the transmitters would be mounted), the district ultimately concluded that TVWS didn't provide the bandwidth needed to support real-time remote learning. The 6 MHz TV channels were insufficient, primarily because at that time the TVWS equipment was not able to bond non-adjacent TVWS channels to increase overall throughput.

After the 2017 voter referendum freed the district from the state-level prohibition on public networks, Moore and BVSD began seriously considering CBRS technology, which the FCC had by then approved. The free, unlicensed general authorized access (GAA) portion of the band provides 80 megahertz (between 3620-37050 MHz), enabling wide channels with sufficient bandwidth and propagation to offer cost-effective connections despite the distances between student homes and the geography of the region. Moore explored a partnership with LiveWire, a private local WISP. Jim Hinsdale, LiveWire's CIO, had begun offering commercial fixed wireless services in the Boulder area in 2010 using unlicensed spectrum in the 3 and 5 GHz bands. LiveWire, like many WISPs, had begun exploring TVWS and CBRS as potential network expansion technologies.

BVSD officially entered into a public-private partnership with LiveWire in 2017, and began a pilot project that started with one CBRS antenna mounted on the roof of Alicia Sanchez Elementary. They expanded to an additional school in 2018 and again in 2019. The COVID-19 pandemic led BVSD to accelerate the roll-out into a district-wide deployment. BVSD outfitted a total of 19 schools with CBRS antennas by the end of summer 2021, extending the network's coverage to the majority of student homes.

Unfortunately, by early 2022, BVSD's continued buildout was stalled by unprecedented wildfires in the area, and by labor and supply chain shortages. Despite these challenges, BVSD and LiveWire had deployed a total of 30 base station radios by February 2022 and predicted completion by the end of 2022. Moore explained that CBRS base stations will be deployed at a total of 44 schools-as-towers, completely covering all of the district's student households.

Technology

The district owns over 100 miles of fiber funded by a public bond. BVSD contracts with the local private company Zayo to manage this fiber backbone. Unfortunately, BVSD is unable to use this extensive fiber network—despite its excess capacity—to connect students at home due to E-Rate restrictions. The CBRS radios mounted at BVSD schools are backhauled using district-owned fiber—extending the network to students when they are not in school—but as a result the district loses E-Rate funding since it must allocate the CBRS network's portion of the cost to comply with FCC rules that restrict E-Rate subsidies to on-campus connections.

The BVSD ConnectME network uses only CBRS spectrum to connect students, and the district owns all of the equipment deployed. LiveWire's co-located commercial offering uses both CBRS and point-to-multipoint Wi-Fi, but students are limited to the district's CBRS portion of the network. LiveWire's commercial CBRS traffic uses the BVSD-owned radios, but they connect through a separate SSID, and LiveWire monitors this traffic. BVSD is compensated annually based on the amount of commercial traffic that routes through their radios (more details provided in Cost & Funding section).

Cambium APs installed on a BVSD school rooftop
Source: LiveWire

The network is using Cambium equipment for the base station access points (APs pictured above) and for the indoor customer premise equipment (CPE). Student households are able to securely connect to the network with their school-issued Chromebooks. Every student in the district receives a Chromebook in fifth grade and ninth grade through BVSD's One-to-Web program. Students receiving free or reduced lunch get the Chromebooks at no cost, and other students pay an annual fee of about $60 per year for four years.

For students within the current coverage area of BVSD's CBRS network, the Chromebooks connect and authenticate to the network automatically via the school-issued CPE. Moore explained that the Chromebooks route student traffic directly to the school networks, utilizing the district's firewall and security measures. Each Chromebook also has web filtering and some classroom management options activated, as well as third party security software.

Student connections are free at the lowest speed tier, which offers minimum throughput speeds of 25/5 Mbps. Households can pay for faster speed tiers for an additional $5 to $15 per month. Moore noted that in August 2021, of the 1,000 student households covered, BVSD had 225 students connecting to the free network regularly. 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 hotspots based on which company's signal is strongest in each respective area. They also help families set up Comcast's Internet Essentials in areas where cable service is available and BVSD's network has yet to reach.

LiveWire and BVSD report reliable speeds and connections from students thus far. LiveWire monitors network performance and provides regular analytics to ensure all segments of the wireless network are operating at proper capacity. During peak hours and periods of intensive usage for remote learning, the network has remained stable, without any major interruptions to date.

Impact

Over the course of four years, BVSD and LiveWire have deployed 32 APs to designated schools in the district, providing connectivity to around 1,000 student households. So far, around 25 percent of covered student households are connecting to the network regularly. Moore notes that is important progress but they are working on outreach measures to ensure more households are informed about the free district service.

Cost & Funding

"I equate internet access to having a pencil – we're giving every student a 'pencil' so they are able to achieve at the level that they can." - Andrew Moore

As a public-private partnership, ConnectME is able to leverage effective cost-sharing mechanisms that make the expansive network less costly to build out and more cost-effective than purchasing ISP subscriptions over the long-term. For the build-out, each CBRS base station site, most of which are installed on existing infrastructure at school sites (typically rooftops), costs approximately $6,000. The total capital costs for the buildout thus far for 19 completed sites is around $264,000. LiveWire covers the installation costs, including construction, frames, conduits and labor. BVSD pays for the Cambium equipment used for the BVSD portion of the network (i.e., APs and CPE). LiveWire is willing to shoulder a large share of the upfront capital investments on the premise that the network will grow and gather more tenants and commercial customers for the ISP.

As noted earlier, the BVSD-owned CBRS base stations are also used to support traffic for LiveWire's commercial connections. The partnership agreement provides that 25 percent of the revenue generated from connections using BVSD radios will be paid to the district annually. Ideally, as LiveWire's subscription base increases, along with the number of connected students, revenue for both entities will rise, making it an even more fiscally sustainable network, as well as potentially providing funding for further investment into the network. For the previous fiscal year 2020-21, BVSD received a revenue reimbursement of just under $10,000. Moore explained that the revenue was expected to be nominal in the first couple years but grow to provide a greater return on the investment and support long-term sustainability.

BVSD and LiveWire have been able to strategically use federal funding to subsidize network costs. Like most commercial ISPs, LiveWire relies on the Affordable Connectivity Program to subsidize (at $30 per month) connections to eligible low-income households. This helps subsidize the network overall, at least indirectly. BVSD received some funding from the Emergency Connectivity Fund to pay for qualifying CBRS equipment. The estimated operating cost for the BVSD portion of the network has not yet been determined, and Hinsdale noted that it's difficult to estimate but likely minimal and becomes less substantial as the network on the whole grows and generates more, offsetting revenue from the fee-paying customers.

Challenges

As detailed in the background section, Moore and the district initially grappled with the restrictions on E-Rate funded fiber and the state of Colorado's restriction on providing any advanced technology service to the public. After the city opted-out of the statewide ban through a voter referendum, Moore ruled out TVWS as an option and eventually pursued a public-private partnership with a WISP to deploy CBRS based on a cost-sharing model that seems financially sustainable over the long term, closing the district's "homework gap" for good.

The partnership has been fruitful, but LiveWire is a small local company and there have been challenges with expediting network buildout. The LiveWire staff is quite lean, reducing their operating costs but limiting their labor capacity. In addition, the region saw unprecedented levels of damage and displacement due to wildfires in January 2022. Due to delays in the buildout, as well as the geographic challenges posed by low density and Boulder's mountainous terrain, BVSD has had to rely on cellular hotspots for students not yet covered by the network. This proved to be both an additional cost and a less-than-reliable connection for students, in most instances.

Lastly, the district has had some difficulties communicating with students' families and getting them to join the CBRS network. There was some reluctance to change by households already using mobile carrier hotspots that were intended to be interim solutions, as well as a trust component that seems to dissuade families from initially taking advantage of the service. Moore is confident that as usage expands and families have a good experience, these obstacles will be overcome. Additionally, after LiveWire finishes the bulk of the build-out, they plan to put more energy into marketing the network in the community.

Going Forward

BVSD and LiveWire are primarily focused on finishing the full buildout to all 44 of the designated school sites. Having completed 25 distribution sites in 2021, Moore and Hinsdale are planning to have the remaining 19 sites installed at schools sites by January 2023. At that point, the network will provide coverage across the entire district. Moore is also working with Zayo to expand on their existing 100 miles of fiber backbone, to further extend coverage to neighboring communities.

Key Takeaways & Success Factors

- BVSD is demonstrating that a public-private partnership with a commercial wireless ISP is a viable model that can both reduce the district's upfront costs and offset operating costs in the longer term as usage and the WISP's customer base grows.
- A public-private partnership can help to offset the FCC's failure to allow districts the flexibility to use E-Rate funding to address the ongoing homework gap and thereby achieve equity across modern digital learning environments.
- BVSD's public-private partnership helps the broader community by creating a low-cost fixed wireless broadband option, a public benefit that should be considered when setting the capital funding requirements.
- BVSD's established a community liaison network to ensure communities are notified once a school has a new tower installed and operational, as well as a marketing partnership with its private sector partner that helps to ensure that everyone in the community is aware that both students and community can take advantage of the program.

Harris County and Public Library System, Harris County, TX

Network Leads: John Spiers, Program Manager
Robert Foster, Technology Strategy Analyst - Harris County Office of Broadband

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
Approx. 5,500 (pilot phase)	500 (pilot phase)	CBRS (GAA)	Average 35/5	Approx. $5.8M	$875,000	ECF CARES

Unique Qualities

This initiative is a partnership between the county, its library system and nine public school districts. The plan for Harris County Public Library's Project Nitro is ambitious given the size of Harris County, which contains much of Houston and roughly 4.7 million people. The proposed CBRS network, currently in a pilot phase, will span nine school districts and is owned and run by the county. Harris County works in close collaboration with schools to identify students in need and with county libraries to coordinate the distribution of Customer Premise Equipment (CPEs) for students.

Motivations & Background

Project Nitro started in December 2020 in response to the COVID-19 pandemic and the subsequent shift to remote learning. This CBRS educational network solution for student connectivity at home was driven by the Harris County Broadband Office as one of several public initiatives that brought free Wi-Fi to parks, community centers, and more libraries.

Technology

Nitro is derived from the name of the Motorola CBRS base stations (APs) that Harris County is deploying—a total of 31 as of spring 2022. Two of these base stations are mobile units mounted on vehicles for emergency response. Of the remaining 29 base stations, 22 are located on county buildings or other public infrastructure, and the other seven on monopoles (primarily in Houston where there are height restrictions on schools). Each tower is designed to support approximately 300 simultaneous users. The district uses a Motorola tool to map the propagation of the signal from each tower, adjusting it to optimize the coverage of student households. When a new coverage area is live, the school notifies those student households, and they are able to retrieve their CPE from the public library.

The county has purchased 1,000 Sierra Wireless CPE devices, also through Motorola, with SIM cards that automatically connect to the base stations. Harris County is able to monitor the number of connections and total upload and download activity using the Motorola Nitro portal. They also use the SolarWinds app to monitor the network. The traffic for the network runs through a 10 GB connection that is owned by the Harris County library system and is using Comcast to carry data traffic in areas where county-owned fiber infrastructure lines aren't available.

Impact

As of April 2022, Project Nitro had three pilot base stations in operation, connecting roughly 500 students. Another 20 base stations access points (APs) have been fully constructed, coverage areas have been identified, and the county has sent coverage maps to school districts to begin the process of notifying student households that they can retrieve CPEs for the areas in operation. Additionally, another NITRO monopole construction and installation is slated for mid-2022 following a grant from a commercial partner to fund construction in Precinct two of Harris County.

Harris County Office of Broadband and the Public Library found that coordinating the distribution of the Sierra Wireless devices to the students directly through their respective schools (as the most trusted partner) is the best way to increase adoption rates.

Cost & Funding

The network's initial funding came from the CARES Act via the Harris County Broadband Office. Six monopole sites were constructed for locating base station APs that cost approximately $250,000 each, totaling $1.5 million. In stark comparison, the 15 base stations located on school and county existing infrastructure cost only around $100,000 total. The mobile base stations for emergency response being installed on existing County Public Safety/Radio vehicles are less costly as expected and the final radio was co-located on an existing monopole at a community fire station at reduced cost. The county was able to use ECF funding for the purchase of all the CPEs (which are eligible as routers) and Chromebooks for students.

Challenges & Going Forward

Robert Foster, the Technology Strategy Analyst with the Harris County Broadband Office, noted that the relatively short timeline to expend the CARES Act relief funding impacted their planning. If more planning time was possible, costs may have been reduced for the deployment. Not only is planning on a short time horizon a challenge, but deploying an expansive LTE network is incredibly complex—notably the engineering analysis, running fiber and electric lines to base station APs, and the capacity needed for physical deployment of all the network components. Lastly, collaboration between the Broadband Office, school districts, and libraries has been a learning experience. The County Broadband Office found they could effectively communicate with larger school districts that have the greatest need for student connectivity at home, but the schools generally have very limited staff capacity to engage with Project Nitro and to ensure that their students get connected.

Key Takeaways & Success Factors

- The County Broadband Office was able to forge and lead an effective partnership with school districts and libraries to target low-income student households using a CBRS network that leverages county buildings and infrastructure to reduce costs and speed deployment.
- An early and comprehensive evaluation of potential base station sites is key, since the county identified sites that ultimately failed certain installation or structural requirements and had to be substituted.
- Being aware of environmental factors is key; Harris County is located in a hurricane zone, so technical wind loading inspections for both building rooftops and monopoles had to be conducted and this impacted final site selection and costs.
- The fact that Harris County has a significant internal technical resource pool with both Wi-Fi and Public Safety Radio expertise is a major advantage that allowed the county to build a total of 136 Wi-Fi and LTE sites in a short 15 months.

HYBRID NETWORKS AND EBS: COMBINING LICENSED AND UNLICENSED TECHNOLOGIES

Lindsay Unified School District (LUSD) - Tulare County, CA

Wi-Fi, CBRS, EBS technologies

Network Lead: Peter Sonksen, Network Administrator

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
4,300	Approx. 3,000 students	Wi-Fi (unlicensed) CBRS (GAA) EBS	Wi-Fi: 15-25/3-9 CBRS: 15/6 EBS: 10/3	Wi-Fi: $250/AP (59 sectors- 2 or 3 each sector) EBS: $15,000/ sector (x8) CBRS: $5,000/ sector (x16)	Approx. $75,000	CARES ECF

Unique Qualities

Lindsay Unified School District (LUSD), which serves an overwhelmingly low-income farming community in California's Central Valley, is perhaps the only school district to successfully design and deploy a robust three-tiered network that combines point-to-multipoint (PtMP) Wi-Fi, CBRS, and Educational Broadband Service (EBS) wireless technologies to cover the entire district. Each of the three overlapping networks operate on spectrum frequency bands that are free to use—but because they differ significantly in capacity, coverage, and propagation, LUSD uses one or another primarily based on the geographic density of student households in various parts of the district. Most students are connected using the 5 GHz Wi-Fi portion of the network, but the CBRS network works well for homes farther from the town center, while the LTE network operating on EBS spectrum (which has the best propagation but the lowest capacity) is most effective at covering outlying areas and homes beyond the range of both CBRS and Wi-Fi.

The operational costs of the network are almost completely offset through LUSD's transition to a blended learning curriculum that relies on digital and online resources both in school and at home. Discontinuing hard copy textbooks and workbooks has generated substantial savings that LUSD reinvests in the network and equitable connectivity. This sustainable network design and diversification of technology optimizes coverage, quality of connections, and effectively works around LUSD's fiber backhaul limitations. Since the network began in 2015, LUSD has been able to document substantial academic improvements it attributes to a blended curriculum that is feasible and equitable due to the district's ability to completely close the homework gap.

Motivations & Background

LUSD's ambitious initiative to improve student connectivity is a direct outgrowth of an academic goal to fully implement blended digital learning both at school and at home, a goal that requires high-quality broadband that connects students directly to the school's network (**see LUSD background video**). When Peter Sonksen, LUSD Director of Technology, started exploring options to improve connectivity for students at home, about 75 percent of households in LUSD were at or below the poverty level. At the time, incumbent ISPs such as Comcast only provided service to the most densely populated neighborhoods in the district. Many other homes had access to DSL service, but the district found that the incumbent ISP service offerings were ultimately too expensive for the majority of low-income households. When LUSD began constructing its own network in 2015, 80 percent of students lacked internet at home—mirroring the ratio of households that were at or below the poverty line.

The district set out initially to install mesh Wi-Fi access points (APs) in the areas of greatest need, very much like the Wi-Fi networks in East Side San Jose and Council Bluffs, Iowa (the latter also profiled here). A Wi-Fi network of this kind has high capacity, and students are able to connect to the access points (APs) directly from their device and in any location that has coverage. This approach works well in more densely populated areas and the equipment is relatively inexpensive compared to commercial-grade PtMP Wi-Fi network designs or CBRS networks, particularly if the municipality or local utilities offer low-cost siting on street furniture. LUSD estimated it would require 400 to 500 APs to cover the district. However, the district ultimately decided this approach would not meet all of the connectivity and equity objectives of their blended learning curriculum, including sufficient capacity, network redundancy, and connecting all student households, including those in outlying areas or hard-to-penetrate buildings such as multi-dwelling units (MDUs).

LUSD recalibrated, deciding to use multiple wireless technologies to ensure that every student has a reliable broadband connection directly to the school's network. The district also decided that they wanted parents in every student household to have reliable broadband access, so that they can access the online progress reporting and fully participate in their childrens' blended digital learning process.

LUSD decided to connect every student's home using primarily PtMP Wi-Fi where feasible, and to use CBRS and EBS where Wi-Fi is not cost-effective or did not provide a reliable connection. Unlike meshed community Wi-Fi, PtMP technology using unlicensed 5 GHz spectrum—which is what most WISPs use to provide commercial-grade service—transmits at higher power directly to CPEs mounted externally on student homes. To ensure equity, student households can also connect to the private LTE network that blankets the entire district using LUSD's EBS license in the 2.5 GHz band. That lower-frequency spectrum has superior propagation, and is licensed to operate at much higher power, but also has limited capacity since LUSD has only one license.

LUSD has had ongoing support from the county in planning and executing their network plans. The network is primarily for students and education, but it also provides some community access at select businesses or public places. Peter Sonksen explained that at these locations, community members can connect through a separate portal (SSID) that displays the terms of service and a short video about LUSD's educational network and services—providing the community both connectivity and awareness of LUSD's proactive initiative to close the homework gap and promote digital skills.

Technology

Nearly every student household has a fixed external antenna installed at their home that connects to either the school's network via PtMP Wi-Fi or CBRS, depending on which best suits each household. Other households, particularly in outlying areas or homes in MDUs, connect via the higher-powered mobile EBS network. Factors including distance and line-of-sight challenges are assessed to determine which option is best for each household.

For households in less densely-populated areas, CBRS or EBS is typically the better option. The PtMP Wi-Fi works well in smaller coverage areas, where student households are closer together and require higher total capacity. For households beyond the range of either CBRS or Wi-Fi, as well as for families in MDUs or mobile homes that prohibit the installation of an external antenna, students connect to the private LTE network that uses lower-frequency EBS spectrum. The EBS LTE network blankets the entire district and also serves as a backup for all student households. It also allows students to connect to the network from locations away from home. LUSD contracts with a third-party for the initial installation of external CPE antennas for Wi-Fi and CBRS connections. This increases the overall cost of each connection, but it boosts signal strength, transfers the liability to the third-party, and reduces the staff capacity needed for LUSD.

The PtMP Wi-Fi portion of the network operates on unlicensed 5 GHz spectrum and serves the majority of student households—about 900 homes or 75 percent of LUSD students. These households are primarily located in denser areas where 5 GHz works well despite its limited range. Each household has an external antenna installed that is cabled to an indoor Wi-Fi router (the CBRS connections work essentially the same way). The district divided its land area into 59 different sectors that each serve about 30 to 40 homes. The Wi-Fi APs connect between 15 to 30 households each, so that each sector has two or three APs each. All of the APs (as well as CBRS radios) that are not located on school buildings are backhauled by wireless point-to-point links using the 11 GHz band. The throughput speed for student households averages approximately 20/5 Mbps. LUSD chose unlicensed PtMP to cover the majority of student households in need because it is the most cost-effective option in higher-density neighborhoods.

LUSD's CBRS network operates in free-to-use GAA spectrum on the 3.5 GHz frequency band (or band 48), one of many bands that support widely available LTE equipment (450 MHz up to 3.8 GHz). The network consists of sixteen base stations, which together transmit across 16 sectors and serve about 150 student households. These households were targeted for CBRS connections because they are beyond the cost-effective range of the unlicensed Wi-Fi network. Each base station radio tower is able to serve three sectors, which is on average about 60 households (roughly 20 homes per sector). Households are reliably receiving end-user speeds around 15/6 Mbps.

LUSD purposely limits speeds on both Wi-Fi and CBRS networks to load balance in each sector, as well as to adapt to the district's limited fiber backhaul, a result of E-Rate cost allocation restrictions.

Many of the homes using CBRS are in MDUs (often public housing) or mobile homes where there are restrictions on installing external equipment. These locations use indoor CPEs that are AC-powered units and Sonksen noted that the CPEs have higher-gain antennas then most MiFi devices on the market. Higher gain antennas amplify the signal and allow more effective power to improve both download and upload performance. Conversely, low-gain antennas send their signals more widely, resulting in the power being dispersed.

The third and final component is the private LTE network that uses LUSD's licensed 2.5 GHz EBS spectrum (band 41). EBS base station radios can operate at much higher power than the transmitters relying on unlicensed or CBRS bands, but with the downside that the channel has limited bandwidth. This same band is used heavily by T-Mobile for its 4G and 5G LTE mobile networks. LUSD's private LTE network covers roughly 26-to-30 square miles, and is used for macro coverage. Because the EBS network broadcasts internet access over a very wide area, it is primarily a backup network for when students are outside of their homes, or if the Wi-Fi or CBRS networks undergo maintenance or technical difficulties arise.

Importantly and similar to the CBRS network, the EBS network serves students living in rental housing that prohibits the installation of equipment at the premises, and those that are not within range of the CBRS radio towers or Wi-Fi APs. LUSD estimates that there are about 100 to 200 households connecting to the EBS network on a regular basis. These households are using AC powered indoor CPE devices and the district is trying to provide every household with two separate SSIDs. One is a secure SSID for the school device that connects to the household CPE, and the other is for general use, which allows students and their families to connect outside of their home when they are in range.

Impact

Over the past five years, LUSD has established and refined a robust network with built-in redundancy that ensures reliable connections to every student household. Of the roughly 4,300 total LUSD students, approximately 3,000 households rely on LUSD's network for internet service. Not only has LUSD achieved impressive coverage, but they are providing end-user speeds that reliably support remote learning activities (primarily real-time video streaming) that require sufficient upload and download bandwidth.

Education Outcomes and Parent Involvement

A unique component of LUSD's model is that the district has primarily funded the operating costs of the network through a transition to blended digital learning. The district no longer uses hard copy textbooks, and the savings associated with going all-digital covers nearly all of the network's annual operating costs. This model not only ensures financial sustainability, but also bolsters educational equity by ensuring students have access to up-to-date and evolving (digital) learning resources. The district has also found measurable improvements in graduation rates, college attendance and test scores since the transition became fully implemented. Lastly, it's a sustainable model not only financially but environmentally, reducing the use of finite raw materials for textbooks and other materials that can be delivered digitally.

Cost & Funding

The total cost of the network in the near term as well as the long term is quite modest considering the impressive breadth of the network's coverage and the bandwidth it provides. The approximate total initial cost of the three-tiered network, including equipment and installation, was roughly $800,000 ($266/student). Overall, based on 3,000 student households connected, this represented an investment of $266 per student to ensure a reliable and redundant broadband internet connection to support remote learning and, more broadly, LUSD's blended learning curriculum. The capital cost for the network buildout has been funded through the district's general budget, as well as with some Federal funding during the pandemic (CARES Act) to purchase CBRS equipment.

COMPARISON OF ESTIMATED TOTAL COSTS

TIME PERIOD (YEARS)	COMMERCIAL SERVICE ESTIMATED TOTAL COSTS	LUSD PROJECTED TOTAL COSTS
1	$900,000	$800,000
5	$4,500,000	$1,220,000
10	$9,000,000	$1,745,000

Buildout vs. Subscriptions: One early impetus for building the network, Sonksen related, was a comparison of the cost to purchase wholesale hotspot subscriptions on a monthly basis with the upfront (capital) and operating costs of a wireless network relying on free unlicensed spectrum. The table just above—provided by LUSD—reflects a rough comparison of the total cost of the two approaches over a one-year, five-year and 10-year time frame. These estimates are roughly consistent with the economic study by Dr. Raul Katz that OTI and the SHLB Coalition released as a companion to this report.

With capital costs and operational costs combined, over a 5-year period, an internet connection for each student cost's LUSD roughly $1,220,000. Compared to a mobile hotspot plan that charges roughly $20-$25 per month per student, LUSD is saving $1,093 per student over the course of five years, and arguably providing a much more robust and reliable internet connection.

As ECF and other temporary funding sources become unavailable, schools will become fully responsible for any and all costs related to connecting students off school property, none of which are eligible for E-Rate discount under the FCC's current rules. In rural areas, such as Lindsay, carriers were not even able to provide the necessary bandwidth or signal strength to support remote learning for 3,000 students simultaneously, making the network not only a better option economically, but a necessary one to simply ensure students have reliable connections.

Capex: Overall the Wi-Fi (point-to-multipoint) portion of the network is the most cost-effective option for connecting as many student households as possible with adequate speed and capacity. Each of the 16 sectors for the CBRS portion cost about $4,000 to $6,000 each for the base station radios, wiring, and installation, but they serve many fewer students per sector than the Wi-Fi network, making CBRS more expensive on a per-connection basis. The base stations vary in cost depending on siting. Seven of the nine were simple installations, colocated on existing light poles or on existing buildings. Two locations required the erection of 80-foot towers, which cost around $80,000. The Private LTE network using EBS spectrum is less expensive overall because there is no installation of an external antenna at homes, but it also provides limited bandwidth and is therefore not a viable option to serve a majority of LUSD's households.

An important component of LUSD's network buildout is that they contracted with a third-party company to install the external antennas at student homes for those that connect with Wi-Fi or CBRS. Sonksen explained that although this adds an additional expense of about $200 to $300 per home, the benefits include improved reliability, avoiding school district liability for the installations, and reducing the technical staff overhead needed by LUSD to deploy the network.

Opex: The network's operating costs total roughly $75,000 annually, which is about $17 per student. The largest cost is the field technician that LUSD employs for day-to-day maintenance needs. Sonksen pointed out that over the six years since the first phase of the network was brought online, damaged equipment costs have proven to be low and most of the network equipment has been very reliable. Some of the Wi-Fi APs from the first phase of the network build have been in operation for the entire six years with no problems. Given this reality, Sonksen said LUSD's timeline for replacing APs is more dependent on the need or desire to upgrade capabilities as technology improves, rather than having to replace them due to inoperability.

The district cost-allocates its fiber backhaul to leverage E-Rate funding and to avoid a redundant fiber subscription cost. E-Rate's cost-allocation method allows LUSD to take advantage of lower rates for fiber and to keep overall E-Rate ineligible costs to a minimum. This is a workable option, but it does ultimately constrain LUSD from offering even greater speeds to the off-campus portion of the network, leading them to throttle throughput speeds in both the Wi-Fi and CBRS portions of the network to load balance due to the effective metering of their backhaul use.

Challenges

District officials initially set out to cover the entire district using just a meshed Wi-Fi system with roughly 400 to 500 APs. But they quickly realized that the student need was much greater and more geographically dispersed than anticipated. They also discovered other obstacles, such as the inability of 5 GHz Wi-Fi to penetrate certain MDUs and prohibitions by landlords on mounting external CPE antennas.

After exploring other options, LUSD pivoted to a point-to-multipoint Wi-Fi network architecture that transmits more directly to an external antenna at each household, which amplifies the signal compared to transmitting directly to a student device indoors. When private LTE using the free GAA portion of the 3.5 GHz CBRS band became available in 2020, LUSD added CBRS deployments for homes out of range of the Wi-Fi APs. Both CBRS and Wi-Fi PtMP deliver more robust connectivity when homes have an external antenna, so the district made that standard wherever feasible despite the extra cost. Lastly, the district has licenses for two channels of EBS spectrum (potentially 40 megahertz) that they used to deploy a Private LTE network that blankets the district with over 30 square miles of coverage. The LTE network allows students to connect from any location in the coverage area, provides an option for locations prohibiting external antennas, and offers a stable back-up network.

Going Forward

LUSD plans to gradually upgrade their PtMP Wi-Fi equipment to take advantage of the capacity boost possible by using the newly available 6 GHz unlicensed spectrum—upgrading area-by-area to spread the costs over a longer period of time. Sonksen also noted that the capacity upgrades would be strategically targeted to the oldest sectors and those most in need of increased speeds. If a sector only has a few households being served by an AP operating in 5 GHz, that would be sufficient for a longer period of time as compared to a sector supporting many more households per AP.

LUSD also hopes to upgrade households to CPEs that support both CBRS and EBS spectrum bands to 5G at some point. At the moment, the technology is available but too expensive to be a viable option. LUSD is collaborating with Dell Computers to produce student laptops that have built-in wireless cards that automatically connect to the EBS LTE network when needed. Lastly, the district is currently phasing out their Huawei equipment and upgrading their two main LTE towers to Massive MIMO technology. The upgrade with the improved antennas has the potential to increase speeds by nearly 600 percent. Completion of the upgraded massive MIMO LTE towers is planned by the beginning of the 2022-2023 school year.

Key Takeaways & Success Factors

- Lindsay USD strategically combines three wireless technologies that utilize free spectrum access—Wi-Fi, CBRS and EBS—to achieve district-wide coverage in a predominantly low-income agricultural community and in a manner that optimizes robust connectivity and capacity depending on location.
- Lindsay has most recently enhanced network quality for students at home by installing external CPE antennas at most households where feasible.
- Annual operating costs are almost completely offset through LUSD's transition to a blended curriculum that is digital-only, which yields substantial savings by no longer using hard copy textbooks or workbooks.
- LUSD has measured substantial academic improvement they attribute to the implementation of a blended digital learning curriculum that is equitable because the district's homework gap is now completely closed.

Imperial County Office of Education (ICOE), “Borderlink,” El Centro, CA

Network Lead: Luis Wong, Chief Technology Officer

STUDENT POPULATION	CONNECTIONS	SPECTRUM	SPEEDS (download/ upload Mbps)	CAPEX	OPEX (annual)	FEDERAL FUNDING
37,375	Approx. 4,500	100 MHz of EBS (2.5 GHz)	30/5	$4.5M	Approx. $520,000	ECF CARES

Unique Qualities

Borderlink is a partnership between Imperial Valley Communications Authority (IVTA) and Imperial County’s Office of Education (ICOE) that offers free broadband to students and the community using primarily LTE technology and Educational Broadband Service (EBS) spectrum licensed exclusively to the county. The Borderlink network is unique in its leadership and funding structure, facilitated by a Joint Power Agreement (JPA) between 35 community anchor institutions, 16 of which are school districts. ICOE is the administrator. This consortium pools infrastructure (i.e., fiber) and resources (i.e., EBS licenses), while also bringing together a diverse number of partners to contribute to funding the network. IVTA (the name of the JPA) began with a fiber network connecting schools and has since expanded to connect 121 different sites. It offers a robust wireless LTE network for this large county in California’s Southeast corner bordering Mexico and Arizona.

Motivations & Background

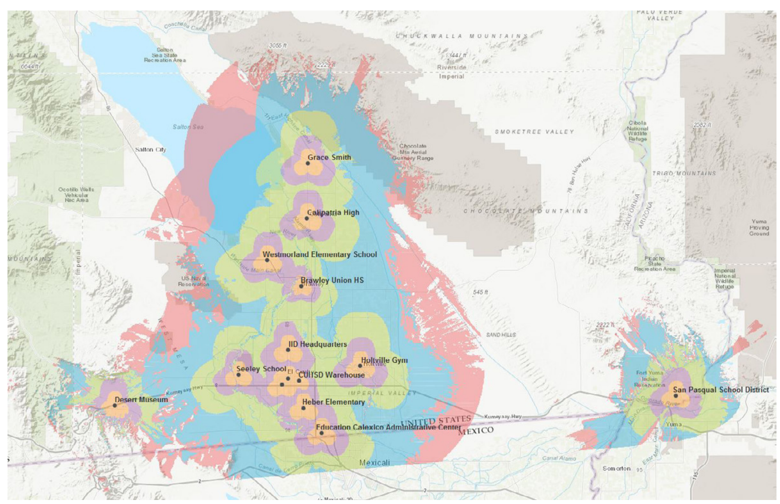
ICOE’s initiative began as an effort to build fiber infrastructure throughout Imperial County after many commercial providers declined. In 2000, ICOE applied for a Federal Innovative Challenge grant with a feasibility plan for their Borderlink initiative that proposed to connect five high schools with high-speed broadband. After winning the grant and beginning a proof of concept, local leaders began supporting ICOE’s effort. At this point, they decided to create the JPA with a simple fixed funding model for the fiber network, which became known as the Imperial Valley Communications Authority (IVTA). The IVTA collaboration includes all Imperial County school districts, city agencies, county agencies, Imperial Community College, San Diego State University-IVC, and the Imperial Irrigation District. As of publication, there are 35 anchor institutions connected to the network, 16 of which are school districts, and around 121 different sites in the county connected to the fiber infrastructure.

In 2018, IVTA began a proof of concept for the wireless network, with plans to locate cell sites near schools using existing towers in the community. By 2019, they had six cell sites completed and shortly after received a USDA Community Facilities grant to expand to 12 total cell sites in more remote areas. Thereafter, it took the county some time to get hotspots distributed so that households in need could connect to the network. Once the COVID-19 shutdowns began, the demand increased rapidly, and many more households joined. To date, ICOE and their partners have distributed about 4,500 hotspots enabled for the EBS LTE network.

Since the pandemic began in spring 2020, ICOE and IVTA have prioritized connecting students. Many schools and superintendents in the county have supported network expansion, and have offered CARES Act funding to facilitate the network's growth and to reach more students. Local colleges and other members have also begun to contribute to expanding the network further. Since 2019, Borderlink has added another seven cell sites, and Wong hopes to reach 22 total sites by the summer 2023 to achieve ICOE's intended coverage goal. At the time of publication, Borderlink had 19 active LTE cell sites and three more under construction.

Technology

ICOE owns its own fiber network, but IVTA also has a 30-year agreement with the power and water utility district for access to a couple strands of their dark fiber, as well as no-cost pole attachments for locating fiber optic cable on utility poles. The agreement also allows ICOE to place wireless equipment in unused tower space. ICOE uses the dark fiber for long hauls between communities and for backhaul to all of the LTE cell sites. The LTE network operates on 100 MHz of licensed EBS spectrum—five total EBS licenses jointly managed by IVTA. The heat map below shows the coverage of the LTE cells, and notes what infrastructure they are located on.



Heat map showing access point (AP) coverage - APs are black dots with labels indicating where they are installed **Source:** Borderlink.org

Students and the community connect to the network with distributed MiFi devices, indoor modems, and via LTE-enabled devices. Some homes or housing complexes that are farther away from antennas connect with an outdoor LTE antenna that can be installed. There is only one SSID for both students and community connections, but school-issued Chromebooks are configured to route every student connection directly to their school's network, which has CIPA-compliant security and safety measures in place. The network has a reliable download speed of 30 Mbps and uploads hover around 5 Mbps, on average. Policies on download and upload speed are evaluated periodically and adjusted to align with the system-wide capacity.

The fiber backbone from IVTA provides 10 Gbps of bandwidth, but Luis Wong, ICOE's Chief Technology Officer (CTO), believes they may need more, given each cell site's potential need for 3 or 4 Gbps of capacity. As noted, each LTE cell has been located on existing tall structures when

when possible. This photo shows an LTE base station radio on the roof of Brawley High School. The project will fund 9 light poles that will also house LTE antennas in the communities of Calexico and El Centro. The LTE network consists of 19 towers that provide around 1,400 square miles of coverage. IVTA also utilizes vertical assets owned by member agencies, such as gymnasiums, radio towers, and buildings with pre-existing connections. ICOE leverages the "Distance Learning Program" to provide a low-cost routing service that allows students to connect via Verizon cell towers that in turn "tunnel" the signal through to the Borderlink network and to the school networks. Borderlink started using Huawei equipment but this has been replaced by higher capacity equipment manufactured by LEAX.

A "school-as-tower" installation at Brawley High School.
Source: Borderlink.org

Impact

IVTA has grown from being primarily a fiber consortium into an expansive wireless LTE network. Today the county and region have 121 sites connected to IVTA's fiber backbone, with around 4,500 hotspots distributed for connecting to their wireless Borderlink network. Wong explained that at any given time, about 2,000 connections are active on the wireless network. When school closures and full remote learning began in March 2020, schools were able to quickly deploy devices to students and the network grew exponentially, providing 10 times as many connections the following fall during all-remote sessions. Nearly 100 percent of the distributed hotpots are for students or student households. Crucially, the network has also been a boon to school budgets—what schools contribute to Borderlink is around one-third of the price they would typically pay to a private ISP for a similar service.

Cost & Funding

IVTAs leadership structure was designed with a flat-fee funding model, which Wong describes as a cost recovery model. IVTA members with a fiber demarcation point at their premises pay an annual fee of $5,250, which covers the roughly $500,000 to $600,000 annual operating budget. This allows the network to offer Borderlink as a free service to its members' users. Wong recognizes that some of these cell sites and fiber demarcation points support many more connections than others. That said, the consortium model offers economies of scale which translates to relatively low costs per connection for all users—as noted above, Borderlink contributions are around one third of what schools would typically pay a private ISP.

The buildout cost for the LTE network and the current 16 active cell sites totaled approximately $4.5 million. The network was originally deployed with Huawei equipment, which cost around $100,000 per cell site for the equipment and licenses. ICOE recently completed the process of replacing that equipment due to security concerns and regulations. The new LEAX cells and licenses will cost about $150,000 per site, including some additional costs for centralized equipment. IVTA's agreement with the power and water utility district to co-locate cells on their existing towers reduced the deployment's upfront capital and labor costs. As noted, the IVTA has a tunneling agreement with Verizon that enables them to use their cell towers as long as the signal traverses through Borderlinks's network. There is no cost for setting up the tunnels, but it does require that Borderlinks's equipment has the ability to terminate the VPN tunnel. ICOE was able to repurpose their existing firewall to have this termination ability. This tunneling agreement helped reduce the cost-per-connection for ICOE and Imperial County Districts to approximately $10 per month.

The hotspots distributed to individuals to connect to the LTE network cost $120 each, or roughly $540,000 in total thus far, with more to be distributed soon. Three full-time employees manage the day-to-day operations of IVTA and ICOE also contribute time and resources when necessary. Overall, it's quite a lean operational staff, and Wong estimates that Borderlinks's annual labor costs for the entire network, maintenance, and continual build-out, are $500,000 to $600,000 annually.

Challenges

Most recently ICOE procured new LEAX LTE cells to replace the existing Huawei equipment. Wong explained that replacing all of the existing cells rapidly was a heavy lift but is ultimately a net-positive for the network since the new equipment is an upgrade that provides faster speeds.

The pandemic created numerous challenges that included difficulty sourcing equipment and materials, creating long delays and increasing costs. The installation requires specialized crews which are usually in high demand from the commercial mobile carriers.

IVTA and its members are also considering restructuring the fixed funding model to make it more equitable for all contributors to the network. IVTA members are actively analyzing long-term sustainability options, with the goal of adopting a new funding model in 2022-2023.

Going Forward

As noted, Borderlink currently has 19 LTE cells in operation and they have 3 more under construction. Borderlink has also ordered more hotspots to distribute to schools and the community. ICOE looks forward to partnering with other government agencies so they can leverage this wireless infrastructure afforded to them. ICOE is considering increasing the current 10 Gbps capacity of the fiber backbone to provide more capacity to each cell tower, and ultimately improve user speeds.

Borderlink has considered pursuing a separate wireless initiative in nearby Winterhaven where ICOE does not have a license for EBS spectrum. A CBRS network model is an option, which would have the potential to expand to a nearby Native American reservation that lacks robust connectivity. For now, they have paused the planning of this extension of the network due to some technical hurdles and to ensure proper coordination between all parties so mutual benefit from the network is achieved. The county also shares information and experience with neighboring Kings County, which has also built out a wireless network on EBS spectrum.

Key Takeaways & Success Factors

- Multi-agency collaboration led by the Imperial County Office of Education proved a very effective way to leverage community assets, to build a wireless network on top of public fiber, and to minimize the cost of connecting students at home (which is about one-third the cost of purchasing ISP subscriptions).
- Developing strategic partnerships with private industry, including a mobile carrier, assisted with technical implementations of the system.
- Access to licensed wireless spectrum proved to be an important foundation for the network, particularly in this large and rural county.
- Access to fiber optic backhaul and a public building or tower at each cell site is crucial to delivering high-capacity services.
- Developing a sustainability plan in the early stages helped stakeholders understand the investments needed to ensure long term success.