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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

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## 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.

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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
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## 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 without home access to internet or devices. The ECF appeared to endorse SHLB's **"To-and-Through"** philosophy, which promotes leveraging anchor institution broadband to connect the surrounding community to "the internet".

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

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

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

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

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

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

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# EXECUTIVE SUMMARY

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

Three options are available:

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

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

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

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

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

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

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

| | CAPEX | OPEX (ANNUAL) | NPV (OVER 5 YEARS) | COMMENTS |
|---|---|---|---|---|
| **1.** Purchase public LTE service from a commercial service provider | $ 4,465,000 | $ 10,260,000 - $ 6,840,000 | $ (46,770,000) - $ (32,688,00) | • CAPEX is based on acquiring wireless broadband Mi-Fi equipment<br>• OPEX ranges are driven by alternative wireless plans (from $ 45 to $30)<br>• 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 uncovered users 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 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, 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-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

# 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 long term when compared to deploying fiber-based options.

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, Cali.'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 might also suggest 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 11-1. 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<br>• 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.

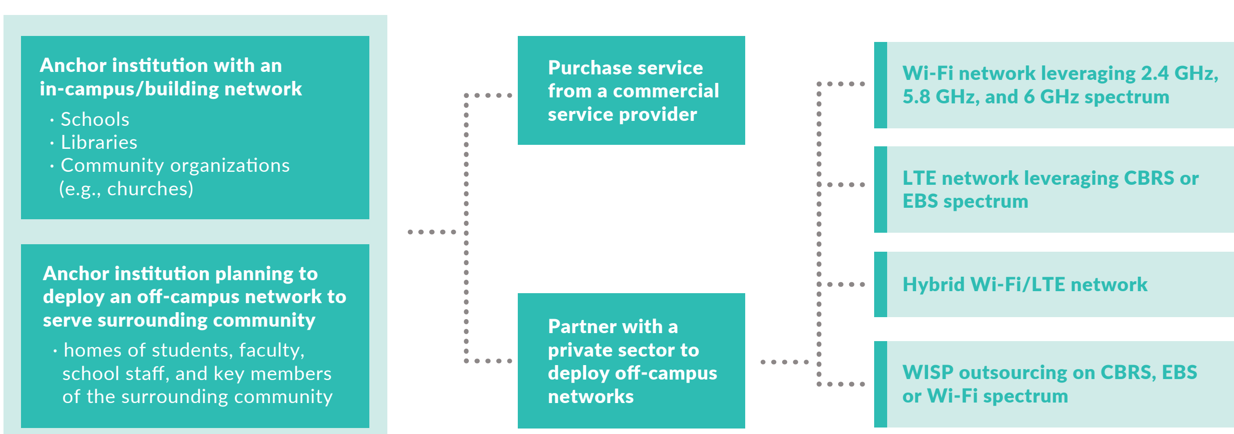
Further, the final decision on wireless technology or the scope of a deployment can, in some cases, entail a combination of two options. For example, if the owned network cannot fulfill the full coverage of the target community, the anchor institution might choose to purchase service from a commercial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



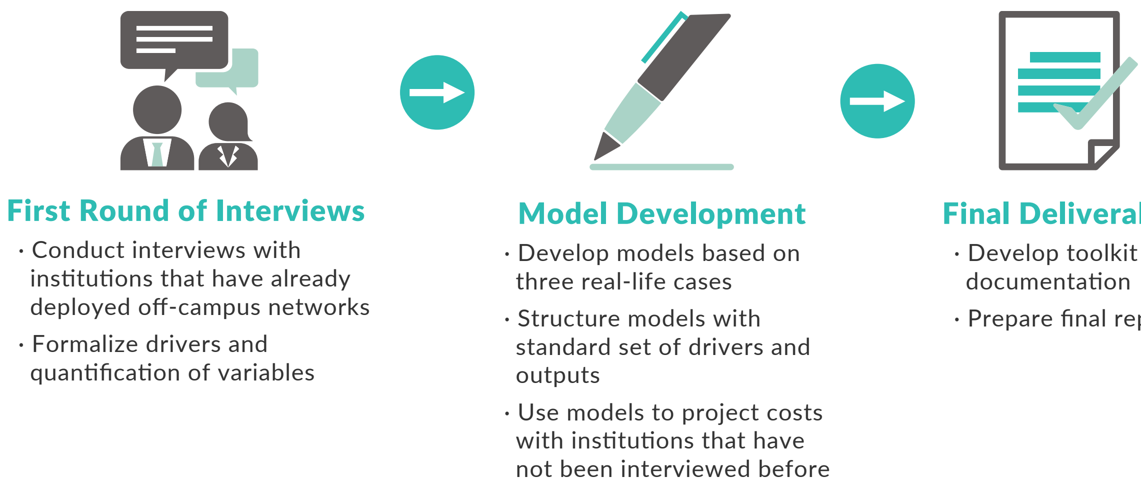

**Source:** Telecom Advisory Services analysis

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)<br>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.

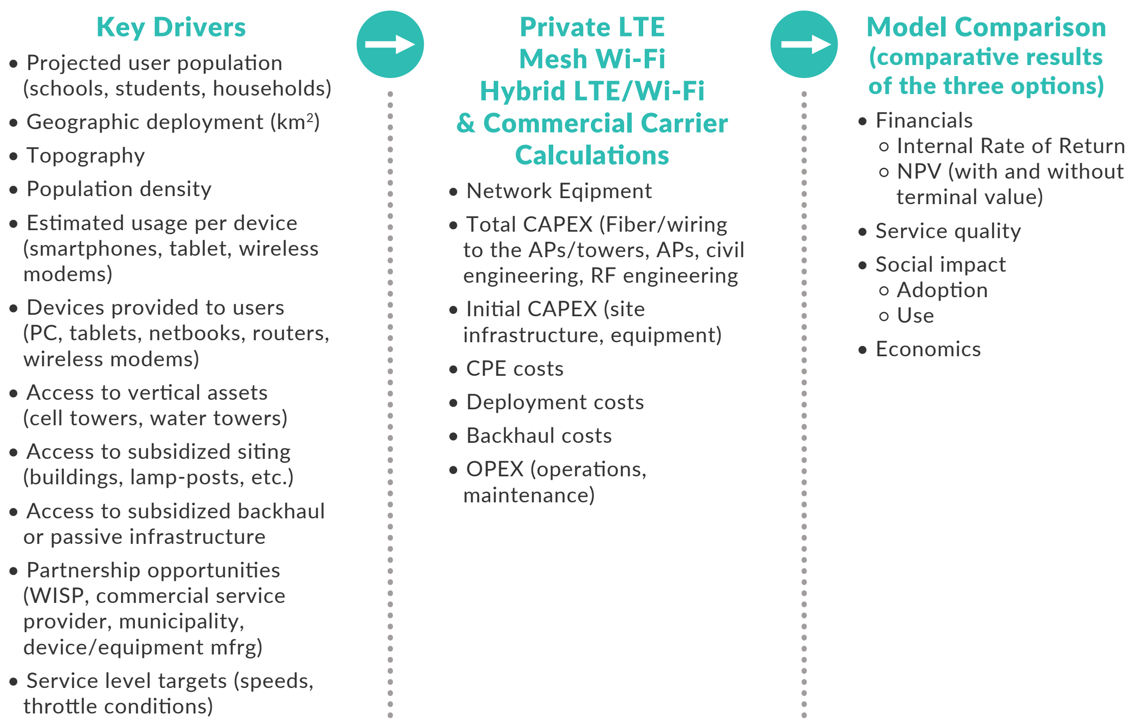
However, for the models to be integrated within a unified toolkit (in other words, being able to be compared apples-to-apples), the “real life” economic models were modified in several dimensions:

- **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 3: Toolkit model structure (example)**




**Source:** Telecom Advisory Services analysis

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

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

# III. PRESENTATION OF RESULTS

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

## III.1. MODEL DRIVERS

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

### Table III-2. Economic model drivers assumed in model

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

**Source:** Telecom Advisory Services analysis

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

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

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

**Table III-3. Structural and technology options**

| TECHNOLOGY OPTIONS | STRUCTURAL OPTIONS: PURCHASE SERVICE FROM A COMMERCIAL WIRELESS SERVICE PROVIDER | STRUCTURAL OPTIONS: CONTRACT OR PARTNER WITH A NON-TRADITIONAL SERVICE PROVIDER | STRUCTURAL OPTIONS: SELF-PROVISION |
|---|---|---|---|
| LTE | Purchase public LTE service from a commercial service provider | | |
| CBRS | | Contract a CBRS based WISP | Leverage CBRS spectrum to deploy an LTE private network |
| EBS | | Contract an EBS based WISP | Use EBS Spectrum |
| White Space | | | Use TV White spaces |
| Wi-Fi | | Contract a Wi-Fi based WISP | • Deploy a mesh Wi-Fi network relying on unlicensed spectrum<br>• 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<br>• 5G Play More Plan 50 GB then unlimited data at throttled down speed | $ 45 | $ 4,465,000 | $ 10,260,000 |
| • Verizon jetpack MIFI 8800L<br>• 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<br>• 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<br>• 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, DSA inspection, 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 |

| | | YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 | YEAR 5 | YEAR 6 |
|---|---|---|---|---|---|---|---|
| FINANCIALS | 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<br>• 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 |
| CAPEX | LTE Evolved Packet Core | $ 31,000 |
| CAPEX | Antennas, RF jumpers | $ 227,525 |
| CAPEX | CPE-MiFi indoor single family | $ 288,750 |
| CAPEX | CPE-Outdoor Multi-dwelling | $ 80,000 |
| CAPEX | CPE-Indoor Multi-dwelling | $ 15,200 |
| CAPEX | Total | $ 2,014,697 |
| DEPLOYMENT COSTS | RF design and Planning | $ 150,944 |
| DEPLOYMENT COSTS | Installation | $ 448,611 |
| DEPLOYMENT COSTS | Remote services training | $ 55,000 |
| DEPLOYMENT COSTS | Structural engineering for school mounts | $ 84,444 |
| DEPLOYMENT COSTS | DSA inspector | $ 20,056 |
| DEPLOYMENT COSTS | Electricians | $ 253,333 |
| DEPLOYMENT COSTS | TOTAL | $ 1,012,389 |
| ANNUAL OPEX (IN SOURCE) | SW maintenance and Licenses | $ 150,000 |
| ANNUAL OPEX (IN SOURCE) | Truck rolls to fix vertical assets | $ 50,000 |
| ANNUAL OPEX (IN SOURCE) | Total | $ 200,000 |
| ANNUAL OPEX (OUT SOURCE) | Annual maintenance for Nokia support and software updates | $ 351,852 |
| ANNUAL OPEX (OUT SOURCE) | 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 |
| FINANCIALS (IN SOURCE) | Opex | $ 0 | $ 200,000 | $ 200,000 | $ 200,000 | $ 200,000 | $ 200,000 |
| FINANCIALS (IN SOURCE) | Recurring costs | $ 0 | $ 206,327 | $ 206,327 | $ 206,327 | $ 206,327 | $ 206,327 |
| FINANCIALS (IN SOURCE) | 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 |
| FINANCIALS (OUT SOURCE) | Opex | $ 0 | $ 406,252 | $ 406,252 | $ 406,252 | $ 406,252 | $ 406,252 |
| FINANCIALS (OUT SOURCE) | Recurring costs | $ 0 | $ 412,579 | $ 412,579 | $ 412,579 | $ 412,579 | $ 412,579 |
| FINANCIALS (OUT SOURCE) | Capex | $ 3,027,086 | $ 0 | $ 0 | $ 0 | $ 0 | $ 0 |

**Source:** Telecom Advisory Services analysis

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

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

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

**Table III-11. Structural and technology options**

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

**Source:** Telecom Advisory Services analysis

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

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

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

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

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

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

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

**Source:** Telecom Advisory Services analysis

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

**Table III-13. Mesh Wi-Fi network financials**

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

**Source:** Telecom Advisory Services analysis

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

### III.6. OTHER REMAINING OPTIONS

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

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

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

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

# IV. ECONOMIC AND PUBLIC POLICY IMPLICATIONS

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

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

| | CAPEX | OPEX (ANNUAL) | NPV (OVER 5 YEARS) | COMMENTS |
|---|---|---|---|---|
| **3.** Purchase public LTE service from a commercial service provider | $ 4,465,000 | $ 10,260,000 - $ 6,840,000 | $ (46,770,000) - $ (32,688,00) | • Average monthly subscription plan: $45 - $30<br>• 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 uncovered users 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.

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# 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.**

SERVICE LEVEL REQUIREMENTS

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

**Source:** Telecom Advisory Services analysis

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

### Second Step: Entering Data In The Calculations Tab

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

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

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

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

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

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

**Third Step: Interpreting The Configuration Economic Estimates**

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

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

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

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

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

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

**Fourth step: output comparison**

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

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

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

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

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

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