Santa Clara County Office of Education

Broadband Networks for Addressing Distance Learning and Homework Gap Challenges

JULY 2021

Joint Venture SILICON VALLEY

Broadband Networks for Addressing Distance Learning and Homework Gap Challenges

Purpose

The Community Broadband Initiative at Joint Venture Silicon Valley (JVSV) was created to help develop strategies and tactics that would lower the barrier to entry for communities unserved or underserved by commercial broadband to build their own networks.

At the start of the SAR-CoV-2 pandemic, when the San Francisco Bay Area began their cross-county shelter-in-place orders, students were sent home and school districts were faced with a massive short-term challenge: How to support distance learning for students who lacked adequate broadband access at home. In response, the Civic Technology team at JVSV authored the Concept Paper *Wireless Networks for Rural Distance Learning, Telemedicine, and Digital Inclusion*. (https://bit.ly/DistLearnConcept) The Concept Paper outlined several ideas for providing connectivity, including quickly enhancing the 4G connectivity in neighborhoods to support hotspots.

The pandemic didn't cause the Digital Divide, or the Homework Gap, but it exposed the problem to a wider audience. The problem exists not only in Access and Functional Need (AFN) households, but even in middle-class and upper-class communities in rural areas.

In the end, 4G hotspots proved to be the best short-term solution for many students. They were easy to deploy, well-understood, and affordable with charitable support from wireless carriers. Santa Clara County Office of Education reports that of the 16,000 distance learning connections they created, 14,200 were via 4G hotspots.

Our state and national leaders also understand that robust internet connectivity is critical. Congress' pandemic relief acts (Coronavirus Aid, Relief, and Economic Security Act and American Rescue Plan Act of 2021) included funding for connectivity. An additional $7.1 billion (Economic Broadband Benefit) will be applied toward the problem. As of July 2021, the Biden Administration proposes $65 billion for broadband network expansion in its infrastructure plan, and Governor Newsom included $9 billion for broadband in his proposed California budget.

The primary downside of 4G hotspots is that charitable support was time-limited—in most cases, to the end of the 2020–2021 school year—not all districts were able to secure the same considerations. Eventually, the service plan costs would have to be covered by the districts or the county offices of education. Supervisor Susan Ellenberg (Santa Clara County, District 4) recognized that a long-term solution was needed. This long-term need is especially true as we begin looking towards a post-pandemic world for the 2021–2022 school year, and realize that the continuation of distance learning and hybrid learning models is likely to persist for some time. In terms of at-home connectivity for students, we cannot go back to the way things were pre-pandemic, and for some students in-classroom learning is not an option. In the 21st century, as one education leader stated so eloquently, "Post-pandemic, broadband will be like yellow #2 pencils. It's something schools, districts, and county offices of education will have to provide."

Applicability to the Homework Gap

Even as vaccination rates increase, the threat of COVID recedes, and students return to the classroom, we are still faced with the Homework Gap. This problem existed before the pandemic and—if left unchecked—will continue to plague us in the future. Learning is not done only in classrooms during school hours. Any solution must consider broadband not only for full-time distance learning, but also for hybrid-learning (with some instructional hours in-person, and some school-from-home hours), and homework/study from home.

The Challenge Summary

The challenge was how to provide connectivity in a cost-efficient, repeatable, scalable, and manageable way. Can school districts become broadband providers? Should they become broadband providers? And if yes, then how can this be done? During 2020–2021, a series of pilot projects were undertaken to explore technology options. This White Paper will examine the challenges we faced in those projects, the solutions we applied to address various problems, and discuss ways our work can be applied to a better future for educational broadband.

Partnership Approach

The initial team for this project consisted of the Santa Clara County Board of Supervisors (specifically, Supervisor Susan Ellenberg), the Santa Clara County Office of Education, and Joint Venture Silicon Valley. Over the course of the project, we've added partners from private industry, schools, and school districts.

Overview of Challenges in Building Distance Learning Networks

Broadband networks are a capital-intensive endeavor. Projects in public Wi-Fi, municipal fiber-to-the-home, etc. begin with the best of intentions, then quickly run into management, sustainability, and scaling challenges. Public sector entities (cities, school districts, etc.) typically do not have experience building, managing, and scaling broadband networks—their skill sets lie elsewhere.

Broadband networks, whether wired or wireless, are engineered solutions. The nuances and complexities of working around challenges, choosing the right technologies, navigating a complex maze of regulatory requirements, and optimizing several competing optimization variables are tasks challenging even for telecommunications engineers with years of experience. This is not to say that people working in cities or local governments cannot learn or do this; rather, they typically do not have the experience.

The advent of new technologies that bring capabilities previously unavailable to non-carrier, non-Internet Service Provider (non-ISP) network builders makes these challenges somewhat easier. In the course of this White Paper, we will see that these new technologies are quickly becoming the go-to choice for school districts seeking to provide connectivity for students in areas where commercial networks are not available, or where commercial connectivity is too slow or too expensive.

Wired networks (including fiber optic) are construction-intensive and require a lot of heavy equipment to build. Obtaining the rights-of-way to place wires or fiber on poles or in underground conduits is challenging. Wireless networks can solve some of the problems we encounter in wired networks, but they also face challenges not found in wired networks.

Technology Options

Fiber Optics

Fiber-optic broadband is the gold standard for home connectivity. Capable of carrying vast amounts of data, and effectively immune to disruptions from nearby electromagnetic interference sources, fiber optic forms the basis of our modern internet and our wireless local area network (LAN) and cellular infrastructure.

The downside of fiber optic is the expense; it is by far the most expensive technology, primarily because it almost always requires new construction. Connecting (or "splicing") two sections of fiber together requires special tools and parts. The dream of deploying "fiber to the home" began in the mid-1980s, and four decades later it remains elusive for most households.

Digital Subscriber Line

Digital Subscriber Line (DSL) is a digital data connection that rides on the wires originally deployed for telephone lines to homes and businesses. xDSL refers to the family of DSL types; ADSL, ADSL2+, VDSL, etc. The fastest type, VDSL, can deliver 50 megabits per second (Mbps) downlink, and 10 Mbps uplink, over a standard phone line known as a "pair." In most cases, VSDL is deployed in a "double-bonded" configuration where two phone lines (or "pairs") are used, because most homes already have this wiring coming in from the telephone network.

The downside of xDSL is relatively low performance; the subscriber must be within a somewhat short distance of the network node, and nearby electromagnetic fields from a variety of common sources can disrupt xDSL signals. In many cases the network of telephone wires (both inside and outside of homes) over which xDSL travels is over five decades old, and damage or degradation of the wiring adversely affects performance.

Broadband Networks for Addressing Distance Learning and Homework Gap Challenges

Coaxial Cable

Coaxial Cable (sometimes called Cable Broadband) is a digital data connection that rides on the coaxial lines originally deployed for television signals to homes and businesses. Data over Cable Service Interface Specification (DOCSIS) refers to the family of cable broadband types. The current standard, DOCSIS 3.1, can carry 10 gigabits per second (Gbps) downlink, and 2 Gbps uplink, over a single coaxial cable. Most homes already have coaxial wiring coming in from the cable television network.

The downside of DOCSIS cable is performance. The coaxial cable network was designed so that TV signals to all households were split off from a common line; however, this architecture means that households on a street or block share the same physical channel, and when usage is high (such as during the evening when many households on a street or block are streaming high-definition video for entertainment) the shared line may be overloaded. Also, many households previously installed their own coaxial lines and splitters to add televisions in different rooms, and these modifications can degrade the cable broadband signal and reduce performance.

Wi-Fi

The IEEE 802.11 family of standards for wireless local area networks are branded as "Wi-Fi." Wi-Fi was designed for in-home or in-office use, and has limitations when compared to wide-area wireless network technologies. The advantage of Wi-Fi is that the cost of customer acquisition is effectively zero because nearly all smartphones, tablets, personal computers, and consumer electronic devices include Wi-Fi capabilities—so the only expense is on the access point or base station equipment. Wi-Fi is also reasonably well understood, and most people know how to use it. Additionally, the spectrum it uses is unlicensed, so there's no financial or licensing burden to either the user or the network operator.

The downside of Wi-Fi is that it was not designed for use as a wide-area technology. Wi-Fi operates as an unlicensed technology under regulatory regimes requiring the radios to emit very low radio frequency (RF) output power levels. This implies that Wi-Fi is not a good technology for creating connections over wide areas, and isn't very good for creating connections inside residences.

Also, as mentioned before Wi-Fi is a very popular technology for a wide range of devices, and this popularity leads to spectrum congestion. It's not unusual in an urban or suburban area to see dozens of Wi-Fi access points operating simultaneously on the same channels. Spectrum congestion reduces the speed and reliability of Wi-Fi.

Wi-Fi is not well-suited for managed networks, because it uses a "Connection-Less" technology, where the client device controls the connection to the network. This is unlike "Connection-Oriented" technologies (4G LTE, 4G WiMAX, and 5G NR) where the network controls the connection to the devices. This leads to issues where a client might be near a stronger (and thus better) access point, but it remains connected to a weaker access point until the current connection becomes completely unusable—in network terminology, the network cannot "hand off" the client to a better access point.

In recent years, extensions to the 802.11 family of standards have added support for handoff and other features, and enterprise-class network equipment controllers can emulate some features found in Connection-Oriented technologies. Still, implementation is often vendor-specific, and thus Wi-Fi is not suitable for wide-area networks with large numbers of users.

Management of onboarding and authentication is also an issue in Wi-Fi. Once someone has the network's SSID and password, it is hard to remove them from the network. Typically the administrator must add the Media Access Control (MAC) address of a blocked user device to an exclusion list. To rejoin the network, the user can simply use a different device, or change (via a process called "spoofing") the device's MAC address. Also, recent updates to iOS and Android added "MAC Randomization" features intended to improve user privacy does this obfuscation by regularly spoofing the device's MAC address, and thus MAC Randomization also allows a blocked user to re-join a Wi-Fi network.

TV White Space

Television White Space (TVWS) is a new concept that takes advantage of unused spectrum in the television bands. In the early days of television, the Federal Communications Commission (FCC) assigned channels by geography and metropolitan areas. To minimize interference, the FCC channels assigned to one area were left open in surrounding areas. For example, in the Sacramento area, TV channel 3 is assigned to KCRA, and there are no stations on TV channel 3 in the San Francisco Bay Area. This means that, in the Bay Area, TV channel 3 is unused. The advent of digital television reduced the need for inter-area channel buffers. TVWS puts unused channels to work delivering broadband over wireless networks.

Despite the potential to maximize spectrum efficiency, there are several downsides to TVWS. The first is the wide range of frequencies traditionally used for television requires different equipment for different channels. In North America, broadcast TV channel frequencies range from 54 MHz on the lower end, to 608 MHz on the upper end. It is challenging to engineer antennas capable of supporting such a wide range of frequencies. Typically, a TVWS network designer chooses a smaller range of channels and orders the appropriate antennas, creating inventory and design complexity. The second downside of TVWS is that the National Association of Broadcasters (NAB, the industry group that represents the television and radio industries) has to date lobbied the FCC for tighter regulation of TVWS power levels, especially in urban channel-areas that are close to operational TV stations. With the radio frequency (RF) power constrained, TVWS nodes in urban areas are not able to deliver high-throughput connections. In the final analysis, the heavily regulated nature of TVWS keeps most manufacturers out of the market, and thus TVWS equipment is expensive and sold only by a few manufacturers.

Citizens Broadband Radio Service

Citizens Broadband Radio Service (CBRS) should not be confused with Citizen's Band (or "CB") Radio used by truckers and hobbyists, and made famous by 1970s movies like "Smokey and the Bandit." CBRS is sometimes referred to as "Private LTE" because it leverages the same technology used by licensed wireless carriers (AT&T, T-Mobile, Verizon, etc.) in spectrum bands that are "lightly-licensed." Wi-Fi, Bluetooth, etc. use unlicensed spectrum—we don't need a license to buy or operate our Wi-Fi devices. This is, in fact, a rather radical change that came about only within the last 30 years—most of the time, using any wireless spectrum requires a license from a country's regulatory agency, e.g. the FCC. CBRS repurposes spectrum used by the U.S. Navy for aircraft carrier landing radar.

CBRS base stations (known as CBSDs) must avoid interference to aircraft carriers when they're nearby. In the CBRS system, a Spectrum Access System (SAS) manages all CBSDs, and enforces a tiered access control system. The tiers are "Incumbent" (the U.S. Navy), "Priority Access License" (or PAL), and "General Authorized Access" (or "GAA").

The CBSDs must remain in contact with the SAS at all times. When a CBSD wants to transmit, it first requests permission from the SAS. The SAS communicates with an Environmental Sensing Capability (ESC) which is essentially a network of receivers along the U.S. coastal waterways that listen for aircraft carrier radars in the area. If the channel is clear for use, the SAS authorizes the CBSD to transmit. If the ESC detects an aircraft carrier in the region, the SAS instructs the CBSD to change frequency away from the radar, and the CBSD, in turn, tells all the client devices to change their frequencies.

CBRS also offers a fee-based prioritization system, where a wireless network operator can purchase licenses for some channels—these are the aforementioned PAL licenses. Incumbents have priority over PAL, and PAL has priority over GAA. However, CBRS sets aside some channels exclusively for GAA users, so there's no way for PAL licensees to completely take over CBRS.

CBRS is different from unlicensed technologies and TV White Space in that, by allowing the SAS to coordinate CBSDs and users, it can use higher power levels.

The downside of CBRS is that it's relatively new—final authorization from the FCC occurred in late 2020. As such, the industry is still learning about CBRS. However, because it's effectively LTE, which we know a lot about from our experience with cellular networks, CBRS presents minimal risk. Several vendors are already in the CBRS market, and it has already garnered a lot of interest as a technology for addressing distance learning and Homework Gap challenges.

Broadband Networks for Addressing Distance Learning and Homework Gap Challenges

Incumbent Access	• Federal users, guaranteed access • Incumbents must allow use by lower tiers if spectrum is not currently needed
Priority License Access	• Commercial users, paid access • Higher power may be allowed • Must yield to Incumbent Users
General Authorized Access	• Open access (must subscribe to SAS) • Low power only • Must yield to Incumbent and Priority Users

Figure 1: CBRS Tiering Model

Another downside is that CBRS spectrum availability is controlled by the SAS and ESC network, so special protections are applied to areas near the coast. Networks near the coast must be planned more carefully, and may not be able to operate at full power levels.

Santa Clara County Office of Education Projects

As of this writing, there are three CBRS-based networks in operation, and a fourth is nearing commencement. As each network has its characteristics, and the learning experience from each contributes to the overall progress, we present the networks in chronological order. Currently, there are two school districts in the project: Campbell Union Elementary and Luther Burbank Elementary.

Blackford Elementary

Blackford Elementary is a school in the Campbell Union Elementary School District, in San José CA. It serves students in the neighborhoods of Del Marietta, Barbera-Stokes, Greylands, Northwest Willow Glen neighborhoods, and others.

Overview

Blackford Elementary School (ES) was the first trial site for our CBRS network. It served as a learning platform to test equipment and prove out concepts that might be applicable to other schools.

Challenges

Blackford ES serves students who live in many housing types ranging from single-family and multi-family homes, to condominiums and apartment complexes. The area is variably characterized as ranging from open terrain in the Del Marietta neighborhood to urban forest in the Greylands neighborhood.

Measurements

As part of the proof-of-concept phase, we sought to characterize the environment and confirm the accuracy of our planning tools by conducting drive-testing on the streets in the area, then comparing those results to the predicted performance from our network propagation planning system.

Drive-testing was accomplished by attaching CBRS indoor access points onto cars, connecting the access points (APs) to the Blackford ES site, and performing throughput speed tests at intersections in the area. The speed tests were done using PCs running Ookla SpeedTest via web browser. The PCs were attached to the vehicle-mounted APs via Wi-Fi, so there is likely some uncertainty introduced by the ambient Wi-Fi environment impacting the PC to AP connection. Nevertheless, we were able to get a general sense of the coverage from the trial site.

We also conducted indoor testing of APs and CBRS hotspots. This work was done during the SARS-CoV-2 pandemic, which added complexity as we could not enter private homes to assist the testers with the setup

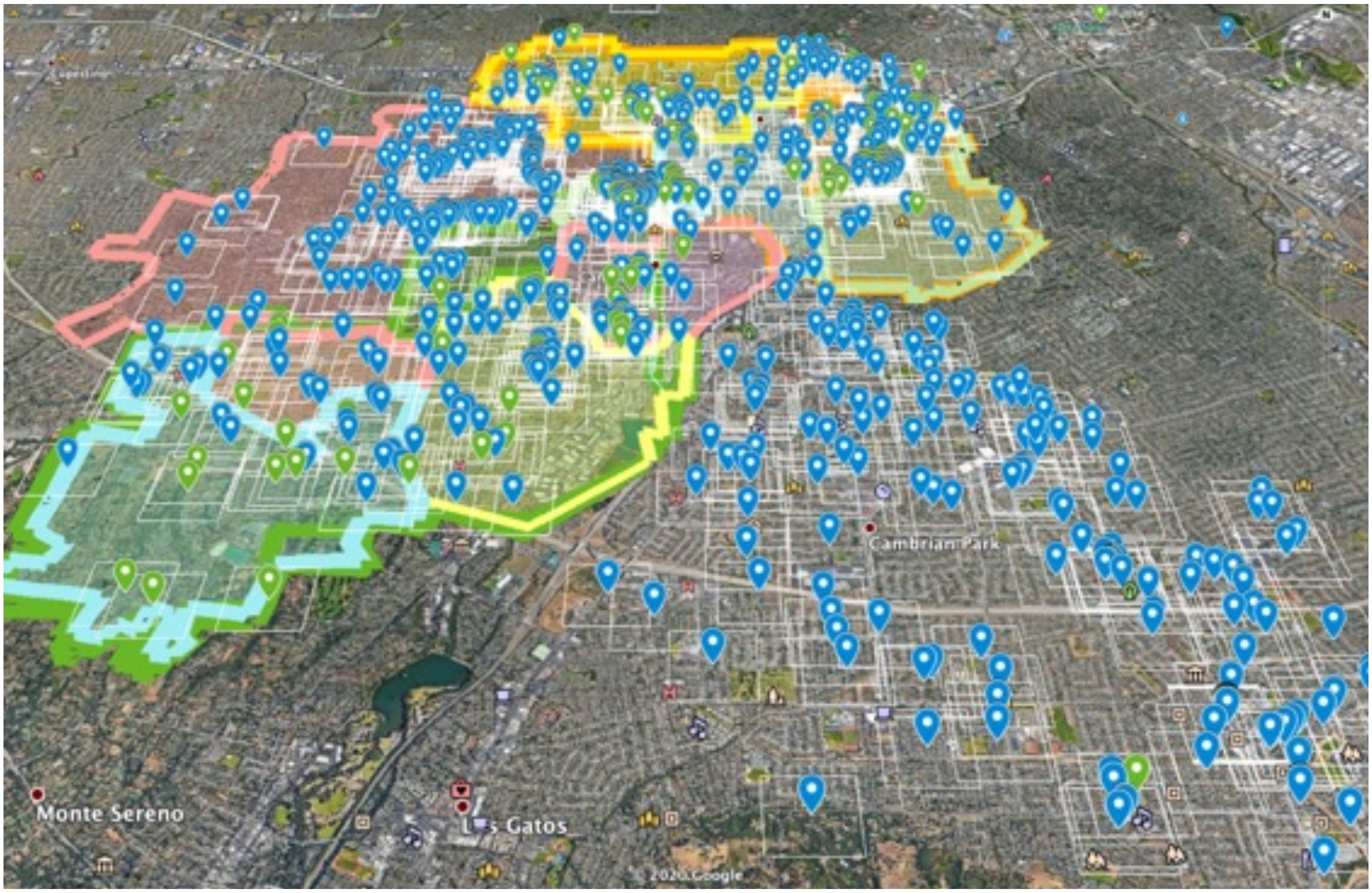

Figure 2: Student Homes vs School Sites

and placement of APs and hotspots. An employee of the Campbell Union ES district has parents who live in the area, so he was able to accomplish some indoor coverage testing at his family's home.

Learning and Conclusions

Given the challenges mentioned, we expected and found the network's performance to be somewhat variable from the predicted performance. In some cases, the signal was almost entirely blocked by dense buildings such as apartment complexes along Stokes Street and the high-peaked roofs of condominiums in the Greylands. The dense foliage in the Greylands also presented challenges. Feedback was provided to Google regarding the accuracy of their propagation planning tools, and they are implementing changes in response.

To mitigate the issues uncovered, propagation simulations were conducted based on several changes:

- Increasing the height of the CBSD antennas at the school site.
- Shifting (in some cases) to outdoor APs.
- Considering additional sites, such as Del Mar High School, to work around building losses.
- Changing to different site antennas with higher gain.

Rosemary Elementary

Overview

Rosemary Elementary School was the second trial site for our CBRS network. It served as a learning platform

Figure 3: In-car Testing for Blackford ES

to test equipment and prove out concepts that might be applicable to other schools. For this school, Joint Venture Silicon Valley acted as the financial agent for the purchasing process.

Challenges

This site encountered a serious issue where a nearby large apartment building, taller than the school, blocked signals to homes in the distance. Indoor coverage in this neighborhood was found to be worse than Blackford, due to the structural profile (stucco over wire mesh) and multi-family nature of nearby residences. It also had issues with vegetation density, likely due to seasonal growth, which affected indoor coverage performance.

Measurements

Drive-testing was accomplished by using CBRS access points attached to a tall mast on a truck, connecting the APs to the Rosemary ES site, and performing throughput speed tests at locations in the area. This methodology was different from the Blackford ES testing method. The test vehicle's mast was approximately five meters high and mounted in the bed of a truck, versus the passenger car method we used previously.

Learning and Conclusions

For Rosemary ES, we again found the network's performance to be somewhat variable from the predicted performance. We again suspected that the Google network planning tool was too optimistic, so feedback was sent to Google requesting adjustments.

To mitigate the issues uncovered, we ran propagation simulations based on several changes:

- Using nearby apartment roofs as sites.
- Shifting (in some cases) to outdoor APs.
- Changing to different site antennas with higher gain.

Castlemont Elementary

Overview

Castlemont Elementary School was the third trial site for our CBRS network. It served as a learning platform to test equipment and prove out concepts that might be applicable to other schools. We also used this site to test a concept for simultaneously augmenting another school's network (Rosemary ES) while also providing coverage for Castlemont students. This was the first site where we installed equipment for two different networks at the same location.

Challenges

Again, we found coverage issues due to nearby buildings and foliage. In this case, the nearby building (a large apartment building) completely blocked the signals in that direction, leading to a complete loss of coverage for students on the opposite side of the apartment building.

Measurements

Drive-testing was accomplished by using CBRS access points attached to a tall mast on a truck, connecting the APs to the Castlemont ES site, and performing throughput speed tests at locations in the area. This methodology was again different from the Blackford ES testing method, the same as the Rosemary ES method. The test vehicle's mast was approximately five meters high versus the passenger car method we used previously.

Learning and Conclusions

For Castlemont ES, we again found the network's performance to be somewhat variable from the predicted performance. Because the Google network planning tool was now considered unreliable and too optimistic, we shifted to a more traditional cellular n etwork planning tool provided by SBA Communications.

To mitigate the issues uncovered, we ran propagation simulations based on several changes:

- Using nearby apartment roofs as sites.
- Shifting (in some cases) to outdoor APs.
- Changing to different site antennas with higher gain.

Luther Burbank Elementary

Overview

Luther Burbank will be the fourth trial site for our CBRS network. It is currently in the design and analysis phase, pending completion of a purchasing agreement then installing equipment. We developed a financial model, using SBA Communications as the system integrator. We are also exploring partnership with San José City College or other county facilities to use their buildings to host additional CBRS equipment for coverage augmentation.

Luther Burbank ES will serve as a learning platform to test equipment and prove out concepts that might be applicable to other schools.

Challenges

Based on previous experience with other schools, we believe that at least one additional site will need to be secured to mitigate propagation issues and optimize towards indoor AP use. We will use the propagation tools provided by SBA Communications, pending Google's adjustment of their network planning tools to account for the optimism we found in previous sites.

Measurements

Until the purchasing is done and equipment is installed, we don't yet have measurements for this site.

Learning and Conclusions

For Luther Burbank ES, we secured fixed-price contract with SBA Communications as the system integrator.

Figure 4: Improved Drive-Testing Rig

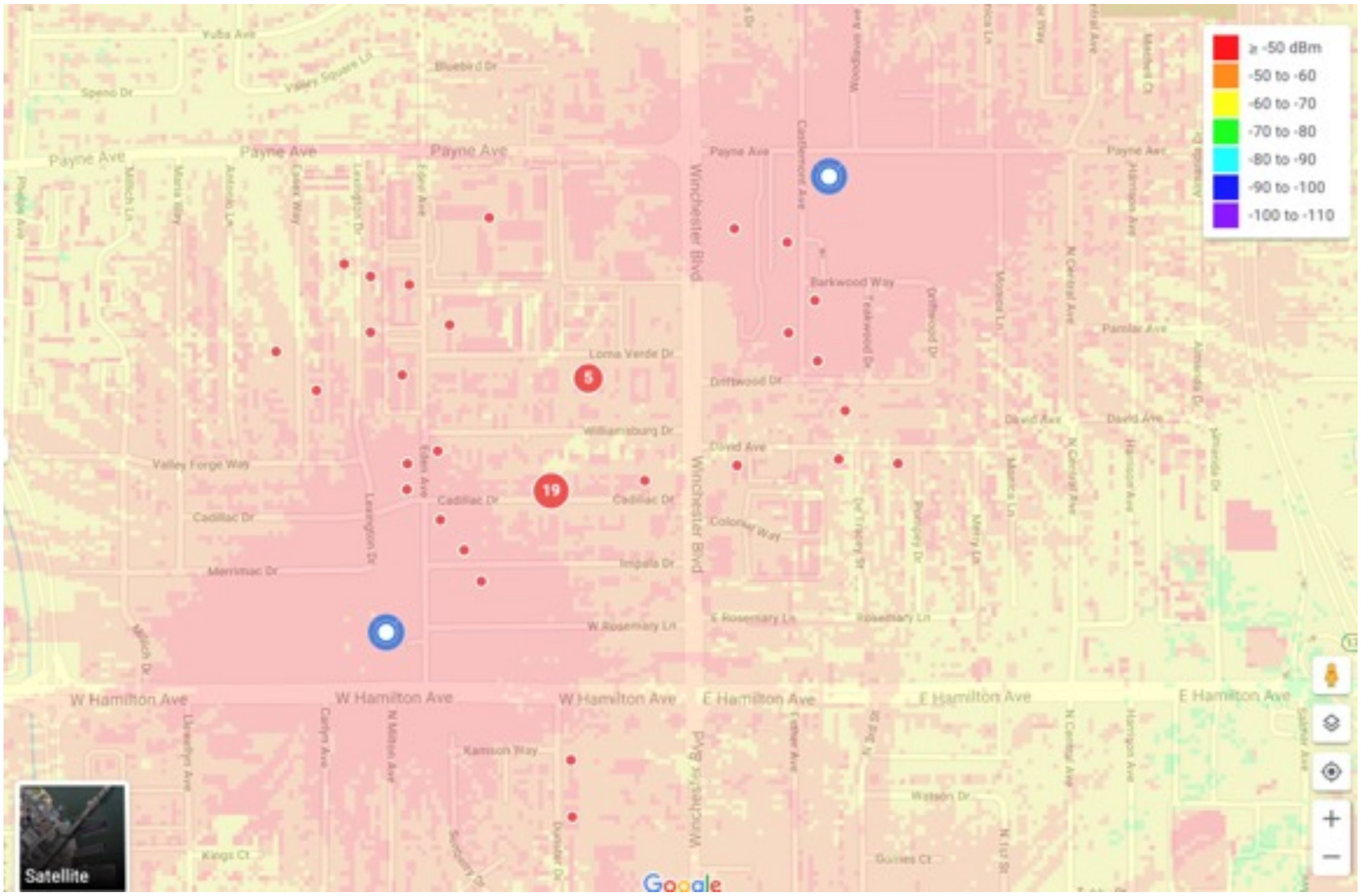

Figure 5: Coverage Estimation Modeling

Summary and Future Considerations

CBRS is relatively new, yet it's already used in a large number of city-owned and district-owned networks to deliver connectivity. This is not unexpected, as the keys to a successful wireless technology are spectrum availability and simplicity of deployment. Wi-Fi was successful as a local-area network technology because of spectrum and simplicity, while TV White Space is not finding success because it's relatively hard to gain permission for access to that spectrum.

Tucson, AZ

During the SARS-CoV-2 pandemic, the City of Tucson (Arizona) deployed a CBRS network for distance learning. Collin Boyce, CIO, reported having to engineer around overly-optimistic coverage models—the same challenge we're facing in our project. The City of Tucson deployed 40 CBSDs, connecting 800–900 users. This is a fairly low user-to-CBSD ratio, certainly much lower than our current ratio. Still, as we work around the aforementioned coverage challenges, our ratio will likely increase and become more like Tucson's.

Reference: https://www.fiercewireless.com/private-wireless/tucson-cio-specifies-biggest-pain-point-private-wireless

Salt Lake City, UT

Salt Lake City's Murray City School District deployed CBRS for K-12 students. They built their network early-on, before CBRS became generally available, using special licensing from the FCC. Also, rather than attempting to cover residences near school, MCSD built the network for on-campus use as an alternative to Wi-Fi and wired Ethernet.

Reference: **https://www.fiercewireless.com/private-wireless/cbrs-private-network-put-to-test-by-utah-school-district**

Mountain View, CA

Mountain View Whisman School District (MVWSD) is exploring CBRS as a technology solution for school-to-neighborhood connectivity. Their network targets to install 14 CBSDs, serving 300 users. Again, this is a fairly low user-to-CBSD ratio. MVWSD's project bears watching, to see if their user-to-CBSD ratio ultimately increases.

Reference: **[https://mvwsd.novusagenda.com/Agenda-Public/CoverSheet.aspx?ItemID=1938&MeetingID=125](https://mvwsd.novusagenda.com/AgendaPublic/CoverSheet.aspx?ItemID=1938&MeetingID=125)**

North Jasper County, IN

The Kankakee Valley School Corporation (KVSC) is building a CBRS network with assistance from Purdue University and several industry partners. A heavily rural area with a low population density, it has 41.2% households considered economically disadvantaged. Thus, the region does not support an economic model for traditional wired (xDSL, cable, or fiber) infrastructure and commercial cellular service is very minimal, so many households lack access to broadband service. In this model, KVSC selects the households and provides level 1 (basic) support. Watch Communications (a local ISP) provides the in-home installation and level 2 support. SBA Communications (a tower and infrastructure provider and site developer) designs, deploys, and operates the network and provides level 3 support to the ISP. The project received significant funding for the pilot project; GEER Funding $140,000, PRF Philanthropic support $150,000, and SBA Communications $500,000.

Looking Forward

Designing a communications network (using any technology) requires careful planning and balancing of goals and objectives against practicalities. In our network projects, we needed to ask the following questions:

- Who does the network serve?
- Is the solution deployable?
- Is the solution replicable?
- Is the solution scalable?
- Is the solution affordable?
- Costs and benefits over other technology options.

Addressing the question of "who does the network serve?" in a sense, this is simpler when dealing with education users. The FCC's E-Rate program makes telecommunications and information services more affordable for schools and libraries by leveraging Universal Service Fund resources, but it also constrains E-Rate networks to specific users—we cannot connect a CBRS network to E-Rate fiber optics and serve broadband to the general public. On the other hand, because CBRS is a connection-oriented technology, it's very well-suited to ensuring E-Rate compliance because the network controller can easily authorize and deauthorize users.

CBRS is easily *deployable*, relative to other technologies. The equipment requirements are relatively minimal, and can be accomplished by people with a basic knowledge of outdoor installation and safety. At a basic level, the radio and antenna installations are very similar to those of an old over-the-air television antenna, amateur radio antenna, or other do-it-yourself installations. Safety considerations are mostly related to adding guy wires (if needed) to the antenna masts for wind resistance, installing proper grounding conductors to dissipate static electrical charges, and lightning protection. And the spectrum access process is both fairly straightforward and relatively low-cost.

CBRS is *scalable* because each site is additive to the existing network. Because the technology is connection-oriented, it's possible to build a county-wide network where any district's CBRS radio can attach to any CBSD. Arguably, this is the direction we should take, because a student from one district who lives near another school in another district can leverage any SCCOE site. A county-wide network also serves the needs of students who are living in transitional circumstances, or who need to connect from different locations at different times of the day.

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Technology	Deployable?	Replicable?	Scalable?	Affordable?	Licensing?	Performance?
Fiber	Utility or local gov't only	Utility or local gov't only	Utility or local gov't only	Cost to Build: High Subscription: Can be subsidized.	None	Very High
xDSL	Utility only	Utility only	Utility only	Utility only Subscription: Can be subsidized.	None	Variable: Ranges from 2 Mbps to 100 Mbps based on condition of the copper lines and wire distance.
Cable	Utility only	Utility only	Utility only	Utility only Subscription: Can be subsidized.	None	Variable: Ranges from 20 Mbps to 200 Mbps based on the condition of the coaxial lines.
Wi-Fi	Yes, requires high AP density	Yes	Yes, if clients are not managed	Cost to Build: High (due to AP density) Subscriber equipment effectively zero cost.	None	Variable, based on technology (.11n is low, .11ax is high) and spectrum crowding.
TV White Space	Yes, requires high AP density	Yes	Yes	Cost to Build: High (due to AP density and limited market)	Yes (FCC application required)	Variable, based on distance between the site and user equipment.
CBRS	Yes	Yes	Yes	Cost to Build: Moderate (due to relatively new technology and early market costs)	Yes, but minimal (SAS subscription for GAA tier is less than $20/ yr./site)	Variable, based on distance between the site and user equipment.

Figure 6: Campbell Union District Personnel Installing CBRS Antennas

CBRS involves an up-front investment that could be challenging to resource, but it will be more ***affordable*** in the long run than purchasing wireless broadband subscriptions from commercial carriers. The costs of replacing damaged user equipment are unknown at this time, but these would be little different than the costs of replacing damaged user equipment for commercial carrier use.

In our considered opinion, CBRS offers the best solution to balance the goals and objectives of a distance learning and homework-enabling network. We'll continue to develop the network and learn as the project progresses in 2021 and beyond.

Next Steps

As we learn more about CBRS from each installation, the solution becomes increasingly replicable. We expect to reach a point where the process becomes a "cookbook" or template within a year or less. During the second year of this project, we will improve the performance of existing networks, build and design additional networks, and share knowledge we develop with others in the educational broadband communities.

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- Vincent Tran, Network Analyst, Santa Clara County Office of Education
- Trevor Walker, Director – Technology Support Services, Campbell Union SD
- Celona (CBRS technology provider and network deployment partner)
- SBA Communications (technology provider, network design partner)

Project Team from JVSV:

- David Witkowski – Executive Director, Civic Technology Initiatives
- Dr. Mohammad Shakouri – Director, Community Broadband Initiative

GLOSSARY

Term	Definition
4G	Fourth generation cellular, an ITU-R definition governed by the IMT-2010 standard.
5G	Fifth generation cellular, an ITU definition governed by the IMT-2020 standard.
3GPP	Third Generation Partnership Project, a standards body.
Access Points	User equipment for Wi-Fi connections, often in conjunction with 4G, 5G, WiMAX, or CBRS backhaul links.
Backhaul	The connection used to link a network nodes to other networks.
Bandwidth	The available RF spectrum in a communications channel or system.
Bit	A single unit of digital information.
Byte	A block of 8 bits.
CBRS	Citizens Broadband Radio Service, a 3.5 GHz band communications standard used in the USA.
CBSD	A network node used to serve CBRS to users and access points.
Cellular	A wide-area mobile wireless technology consisting of many sites interoperating as a network, for the purposes of providing voice and data communications.
Channel Buffers	Physical regions where RF frequencies are left unused, to avoid interference with active communication networks in other regions.
dB	Decibel, a unitless ratio of gain or loss.
E-Rate	A U.S. federal government program to provide reduced cost fiber-optic service to schools and libraries. E-Rate by law may not serve internet connectivity to the general public.
EMF	Electromagnetic Fields, the combination of time-varying electric and magnetic forces.
ERP	Effective Radiated Power, an IEEE standardized definition of RF power, measures the combination of the power emitted by the transmitter and the ability of the antenna to direct that power in a given direction.
ESC	Environmental Sensing Capability, a piece of equipment that tells the CBRS SAS if incumbent users are operating in the area.
FCC	Federal Communications Commission.
GAA	General Authorized Access, a CBRS user tier.
GB	Gigabyte, 1x109 bytes.
GHz	Gigahertz, 1x109 hertz.
Hz	Hertz (cycles per second), a measure of signal frequency.

GLOSSARY

Term	Definition
IA	Incumbent Access, a CBRS user tier.
ICNIRP	International Commission on Non-Ionizing Radiation Protection.
IEEE	Institute of Electrical and Electronics Engineers, a standards body.
IEEE 802.11	The family of standards governing operation and interoperability of Wi-Fi technologies.
IT	Information technology.
LTE	Long Term Evolution, the name for a 4G-compliant radio standard published by 3GPP.
LTE-A	LTE Advanced, a higher performance version of LTE.
Mbps	Megabits, 1x106 bits per second.
MBps	Megabytes, 1x106 bytes per second.
MHz	Megahertz, 1x106 hertz.
NR	New Radio, the name for a 5G-compliant radio standard published by 3GPP.
Offload	A network enhancement technique where parallel networks handle requests for large amounts of data (such as streaming video) – usually through a LTE-U, LAA, or Wi-Fi node.
PAL	Priority Access License, a CBRS user tier.
RF	Radio Frequency.
Roaming	The automatic sharing of networks, used to provide subscribers with a larger number of available sites without requiring user intervention.
SAS	Spectrum Access System, a system that governs channel access and priority in CBRS.
Small Cell	A type of communications equipment that operates at lower power levels than a macro site. Small Cells typically cover areas from a single room up to several hundred meters in radius. They are attached to other structures such as building roof perimeters, streetlights, and utility poles.
Spectrum	The range of RF frequencies used by a wireless system.
Throughput	The amount of data carried by a communications network.
Watt	A measure of power, used to define RF power levels.
Wi-Fi	Wireless Fidelity, a trademark name for the IEEE 802.11 family of data communications standards.
WiMAX	The trademark name for the IEEE 802.16 family of standards for data communications.
Wireless	Telecommunications of voice or data using RF methods.

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