North Carolina Rural Student Home Internet Access Pilot Program

Initial Report

June 30, 2021

NC STATE Friday Institute for Educational Innovation

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The authors wish to thank the dedicated staff at the pilot LEAs, as well as the service providers and equipment manufacturers who have helped to make this research possible under the most trying of times during the pandemic. Without their dedication and willingness to help, this project would not have been possible. The NC Broadband Infrastructure Office, the Department of Public Instruction School Connectivity Initiative team, MCNC, the NC Business Committee for Education, the Office of the State Superintendent and the State Board of Education have all been extremely helpful in our work to solve the challenges of home internet access for all students.

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Executive Summary

In 2017, long before the pandemic, the Technology Infrastructure Lab at the NC State University Friday Institute for Educational Innovation had already begun investigating wireless technologies to provide last-mile internet access to K-20 students, as well as techniques to improve wireless coverage in large campus environments, such as colleges and universities.

Based on that groundwork, in 2019 the Friday Institute suggested to the NC Department of Public Instruction (DPI) that research be undertaken on some emerging technologies which could be used to connect students to the internet while at home, or away from school.

As a result of the pandemic, the NC Department of Public Instruction and the NC Broadband Infrastructure Office (BIO) awarded the Friday Institute research grants to investigate alternative and cutting-edge wireless technologies that could be used to provide rural students with home internet access.

The Friday Institute, already having substantial ties to the K-12 community and significant experience in networking and broadband technology and policy, immediately began work to deploy emerging wireless internet technology to approximately 175 families in four K-12 school districts.

This report, the first to be produced as a part of these research grants, serves to show the progress and expected expenses, and to provide some early findings and recommendations. An additional report with much more quantitative data will be developed in the first quarter of 2022 after all pilot families have had an opportunity to use the home internet service for several months while school is fully in session.

To date, the most successful deployments in the pilot consist of approximately seventy-five SpaceX Starlink Low Earth Orbit (LEO) satellite terminals that have been in use for between one and five months. Preliminary speed test data from these units is very encouraging. While some minor service disruptions have been encountered, most of the families receiving internet access from the Starlink service are overwhelmingly satisfied and their students are using the service daily.

We have deployed approximately two dozen Television Whitespace (TVWS) customer premises devices in cooperation with Hyde County Schools and RiverStreet Networks.

Work on the development of a Citizen Broadband Radio Service (CBRS) pilot in Chatham County is underway and buildout should be ready for approximately thirty families when the new school year starts in the fall of 2021.

Project Overview

The pandemic has highlighted the stark reality that many students in North Carolina simply have no options for home internet access, putting them at a disadvantage to complete homework and develop the modern skills necessary in today's workforce.

In December 2020, the NC Department of Public Instruction (DPI) awarded a $250,000 research grant to the Technology Infrastructure Lab at the NC State University Friday Institute for Educational Innovation to research alternative and cutting-edge wireless technologies that could be used to provide students with home internet access. This initial report as well as a final report due in the summer of 2022 will serve to inform policy makers, DPI, the General Assembly, the State Board of Education and the Broadband Infrastructure Office on the viability and effectiveness of three unique wireless technologies which may be used to reduce the homework gap in North Carolina.

Three school districts were selected based on lack of home internet options in their student body, population density, topography and geographic diversity. Three unique and separate technologies were also selected. Additionally, different deployment models were considered in order to investigate not only the technical capabilities, but the cost models, operational characteristics and sustainability of these technologies.

The three wireless technologies being studied are:

- Low Earth Orbit Satellite (LEO)
- Television Whitespace (TVWS)
- Citizens Broadband Radio Service (CBRS)

An additional grant of $264,000 from the NC Broadband Infrastructure Office (BIO) was also received and specifically used to expand the number of locations at which Low Earth Orbit satellite technology was studied. This funding also allowed us to add a fourth school district to the pilot.

The General Assembly has already created a satellite internet grant program (see NCGS § 143B-1374) which will be administered by the NC Broadband Infrastructure Office. This research will serve to help inform the BIO in the creation of the new satellite internet grant program. The satellite internet grant program will be separate from the already successful GREAT Grant program. The research goals of the DPI grant and the need for BIO to understand the LEO technology better were well-aligned, so the Friday Institute simply expanded the work already underway for DPI to add LEO service for an additional (approximately) one hundred and twenty K-12 families.

Pilot school districts (Local Education Agencies or LEAs) were selected with varying population densities and topographic profiles. The following LEAs were selected:

- Swain County, with low population density and large mountains with deep valleys and extensive foliage in many places which prohibit the propagation of cellular and other wireless signals
- Hyde County mainland, with extremely low population density and expansive flat terrain with limited foliage
- Hyde County, Ocracoke Island, isolated, with medium population density confined to a small (about 2 square mile) area; Ocracoke Island is accessible only by ferry
- Chatham County, with generally low population density except in small towns like Pittsboro and Siler City; Chatham County consists of mostly rolling hills with substantial foliage.
- A fourth county with low population density, extensive foliage and rolling hills is also being investigated for a LEO pilot, but this project has not yet been finalized. The county selected will be north of Raleigh along the border with Virginia.

NCSU quickly issued sub-awards for the bulk of the grant funding to the selected LEAs so that they could procure and distribute the equipment to be tested to parents. This process, in ideal circumstances, would be a challenge. With the added delays and slowness caused by the pandemic, we have been unable to deploy devices to as many students as we had hoped, but we are well on the way to having approximately 175 families connected and ready to test their service later this summer. We cannot stress the importance of engaging the local LEA staff. Without significant investment of time and energy on the part of many local educators and technology staff, this project would not be possible.

This report will provide conclusions that can be drawn from the limited testing completed thus far, as well as observations and recommendations gleaned from the process of this undertaking. The budget for both the DPI and BIO grants are provided in Appendix C. We expect to spend less than $50,000 for staff at the FI to execute this work, with the bulk of the funding going directly to LEAs so that they can procure as many student internet connections as possible for the research.

We are currently in the process of testing SpaceX Starlink Low Earth Orbit-based satellite internet access, Television Whitespace, and Citizen Broadband Radio Service in four LEAs, targeting around 200 families when fully complete. The table below summarizes the pilot projects. Virtually all funding provided has been budgeted and allocated. We do not expect the number of families involved in the pilot to change significantly going forward.

LEA	Technology	Geography & Density	Approximate Number of K-12 Families
Hyde	TVWS	flat, extremely low density	30
Hyde (Ocracoke)	LEO	flat, isolated island, medium density	45
Swain	LEO	rugged mountains, low density	60
Chatham	CBRS	rolling hills, medium density	25
TBD	LEO	rolling hills, low density	30

Technology Discussion

Low Earth Orbit (LEO) Satellite Internet

In the 2017 to 2019 timeframe, several companies filed their applications to launch Low Earth Orbit (LEO) satellite-based internet access with the FCC. To date, the three most notable companies are SpaceX, OneWeb, and Amazon Kuiper. Of the three, only SpaceX, which has launched approximately 1,700 LEO satellites, offers a viable commercial service. All of our work and research has been completed using the SpaceX Starlink service.

When the Friday Institute began investigating Low Earth Orbit satellite internet in 2017, we never thought we would need to learn so much about orbital mechanics and the physics of how satellites work. We were exposed to terms such as "fully demisable" and "satellite constellation", which were not in our lexicon. In this section we will attempt to summarize how Low Earth Orbit satellite internet works and why LEO is nothing like the traditional satellite internet which has been prevalent in rural America for over a decade.

Communications satellites can be thought of as reflectors. A user terminal (satellite dish) beams a signal up to a satellite, which beams a copy back down to Earth, on a different frequency, to a fixed point called a gateway. The gateway houses a high-power antenna array and high-capacity fiber connections to the public internet. The opposite path, and different frequencies, are used for the data ***to*** the user terminal. This is true regardless of which type of satellite (traditional or LEO) is being used.

The key difference between Low Earth Orbit (LEO) and traditional (Geosynchronous or GSO) is in the distance from the surface of the Earth to the satellite. That distance dictates the number of satellites needed to cover all of the United States as well as the overall system capacity, latency and other operational characteristics.

In GSO service, a small number of satellites are placed above the equator at about 22,000 miles out. This special orbital location (technically called "geostationary") allows relatively inexpensive user terminals to be used because they need not "track" a satellite. Once installed, a GSO user terminal simply points to the exact same location in the sky, 24/7 and the satellite moves synchronously with the Earth's orbit. Commonly known GSO services include DirectTV and Dish Network, but many other communications satellites use this orbit and technique. These low-cost dish antennas always point towards a satellite that is in a fixed location over the equator.

There is one, and only one orbit where this magical characteristic of geostationary orbit can occur. That orbital plane, at 22,000 miles above the equator, is a very crowded space. Many communications satellites are crammed in this orbital plane because it is the one place where satellites can be placed that allow inexpensive user terminals to be used on Earth. Any other orbit besides the geostationary orbit means that the satellites are moving relative to the surface of the Earth. You cannot simply place a satellite 500 miles above a city and park it there; the laws of physics simply do not work that way. The result is the need for a constellation of satellites, and satellite tracking technology in each user terminal. These facts make non-geosynchronous orbit (NGSO) based communications much more costly and complex.

In contrast to GSO, Low Earth Orbit, as the name implies, uses a constellation of satellites at a *low orbit*, typically less than about 1,000 miles in altitude. To provide full coverage of the Earth, or even most of the United States, thousands of satellites may be needed. The user terminal for LEO is drastically more complex than that of GSO, since each user terminal must "follow" new satellites every few minutes as they pass overhead. The terminal must then quickly find and lock onto the next passing satellite. The user terminal does this over and over again, endlessly tracking the satellites as they fly over at about 3,000 miles per hour. A great resource to visualize the SpaceX constellation live and understand the orbits is: https://satellitemap.space/ A snapshot of that site is shown below.

Figure 1. Snapshot of a live coverage map of the Starlink constellation. (Source: https://satellitemap.space/)

Since the LEO satellites are so much lower to the surface, the time it takes for the user's signal to reach the satellite and return to Earth is greatly reduced. This means that LEO satellites provide much lower latency and can support live video and audio, commonly needed in remote learning. A typical GSO satellite will have a latency of 600 milliseconds or more, making live audio very cumbersome if not impossible. We have found the Starlink latency to typically be about 50 milliseconds; twelve times better than GSO.

Additionally, since there are literally thousands of satellites in the LEO constellation, the total network capacity is hundreds, if not thousands, of times greater than traditional GSO services. Since there is more capacity, more users can connect to LEO satellites at the same time without impacting each other. This allows SpaceX to offer Starlink service without user data caps that are commonly found in GSO and cellular internet services.

In the past, to track non-GSO satellites, the user terminal would have motors and the dish would physically follow the satellite through the sky. This action can commonly be seen in science fiction movies and NASA videos about radio astronomy. Many decades ago, the military pioneered a technology for radar called "phased array". Using this technique, an array of antenna elements could be used to direct a transmitted signal in a specific direction. An antenna with a large number of individually addressable antenna elements is used. By varying the time between the signal being transmitted on each individual element, the system can direct the transmitted signal without any moving parts. However, the process of calculating the delays needed for each antenna element is computationally intensive and until recently was not available to consumers at a reasonable price. SpaceX has utilized this technology to create a user terminal that is physically fixed in position and direction but uses phased array techniques to track the satellites as they pass overhead. The commercialization of phased array technology for consumers is one of the biggest breakthroughs of the decade and means that affordable (but not inexpensive) user terminals that need not move can be installed in residential consumer environments.

The Starlink service is technically considered a "beta" by SpaceX at this time. This is due to the fact that the entire constellation has not yet been launched. This means there are brief windows of outages with Starlink each day as there will occasionally be a "hole" where no satellite will be visible to a user terminal. The further north the user is located, the smaller the outage windows are. This is due to the nature of how the orbital planes of the constellation overlap. Most of North Carolina is situated such that several times a day a few minutes of outage should be expected, at least for the remainder of 2021. The diagram below shows just such an outage over western NC; there were no Starlink satellites with a "footprint" over western NC when this snapshot was taken.

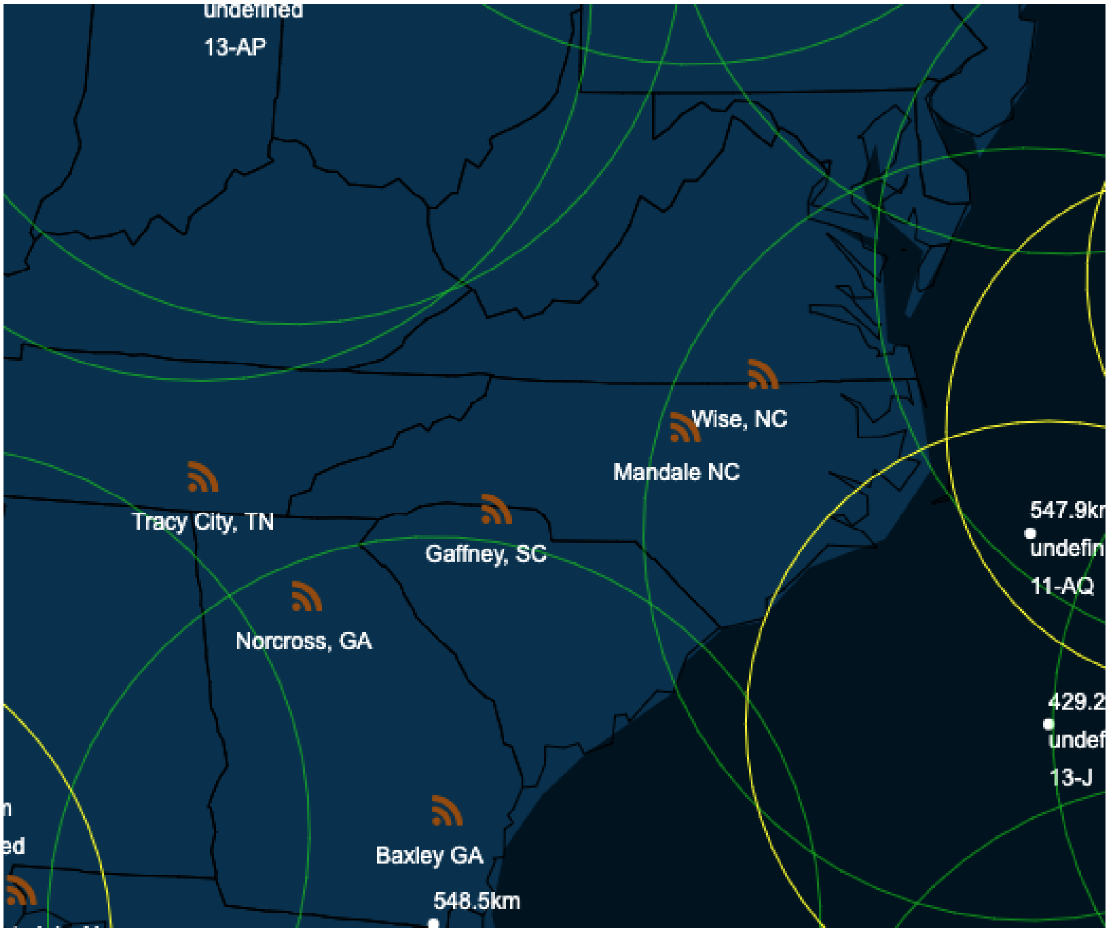

Figure 2. A brief interval when there are no Starlink satellites over western NC (Source: https://satellitemap.space/)

In the above diagram, the locations of Wise, NC and Mandale, NC are the two Starlink gateways located in North Carolina. Residents of North Carolina will likely utilize these (as well as the gateways in bordering states), for service. These gateways have very large capacity fiber connections to the Starlink backbone network and the public internet. As each Starlink satellite passes overhead it is not only "tracking" the gateway but potentially thousands of user terminals too. Every user terminal must track several Starlink satellites as it schedules its "roaming" from satellite to satellite every few minutes. Extensive computation is required to make the system work; it's actually remarkable.

We must also note that there is a concept of Medium Earth Orbit (MEO) satellites, too. We have had discussions with a vendor who will be offering this service, but it is not ready for deployment at this time. MEO is similar to LEO in complexity, but by using a higher orbit (several thousand miles), a smaller number of satellites can be used to provide coverage of the entire planet. The higher orbit means that cost is reduced since the number of satellites is drastically reduced. However, total constellation capacity is also lower since there are far fewer satellites than LEO constellations. MEO will provide an additional connectivity option in the future, although we expect it will be more targeted to commercial uses rather than residential or student access.

Television Whitespace (TVWS)

Over the last decade, and because of the move to digital television in the early 2000's, the FCC has "repacked" TV station operating frequencies such that much of the UHF band (Channels 37 and up) is no longer used by broadcast television. The FCC has made some of these frequencies available via auction to cellular providers (channel 37 and up) and has retained some of the frequencies for use as what are called Television Whitespaces (channels 14 and up). Contrary to the name, TVWS has nothing to do with television, cable TV, or broadcasting. In fact TVWS is much more akin to Wi-Fi but uses a different frequency band, namely the former UHF TV broadcast channels. TVWS is typically deployed on towers or tall structures, like cellular LTE services, and covers a geographic area in the range of a few miles.

TVWS, being in the 470 MHz to 790 Mhz range, is well-suited for transmission through foliage and walls. A key differentiator of TVWS as compared to LEO, CBRS, and many other LTE frequency bands is the ability of TVWS to reach clients that do not have a line of sight (LOS) to the tower. Line of sight can often be a challenge for rural deployments, and TVWS can help mitigate this. In general, the lower the frequency of a signal, the better its propagation characteristics, all else being equal. However, since the bandwidth is limited in TVWS (6 MHz per channel), the total capacity of TVWS transmissions are somewhat limited, relative to other higher frequency technologies.

We selected Hyde County as the first place to consider a rural broadband pilot in 2018, long before the pandemic. We reached out to Superintendent Steve Basnight in late 2018 but did not have funding. We had identified the abundance of TVWS spectrum available in Hyde County, and the very low population density, as ideal circumstances to test TVWS. We had also been researching TVWS products, as well as information about Microsoft's TVWS pilot programs in Virginia. Upon review of technical details, we decided to test the TVWS radio from 6Harmonics and engaged the vendor in technical discussion. The pilot program in Hyde County is using the most current, cutting-edge TVWS product available and we do not anticipate the challenges seen in other locations with previous generation TVWS equipment.

"Bandwidth" refers to the amount of spectrum which a signal may consume. For example, a typical television signal uses 6 MHz of bandwidth. An FM radio broadcast uses 200 KHz (0.2 MHz) of bandwidth. The amount of information needed for the audio-only transmission on FM radio is drastically lower than the information content required to produce a high-definition video. The laws of physics dictate the relationships between bandwidth, power, signal to noise ratio, antenna gain and many other operational parameters. Additionally, the modulation technique, or the way in which data is encoded to a waveform also plays a key role in the effective throughput and the reliability of a signal.

The test site in Hyde County was able to use four bonded channels to create an effective bandwidth of 24 MHz, but this level of bonding is not available throughout the state; in fact only locations east of Interstate 95 have this much contiguous TVWS bandwidth available. The map below highlights the areas of North Carolina that are rich with TVWS spectrum. Blue areas have some available spectrum, and green areas have extensive spectrum available.

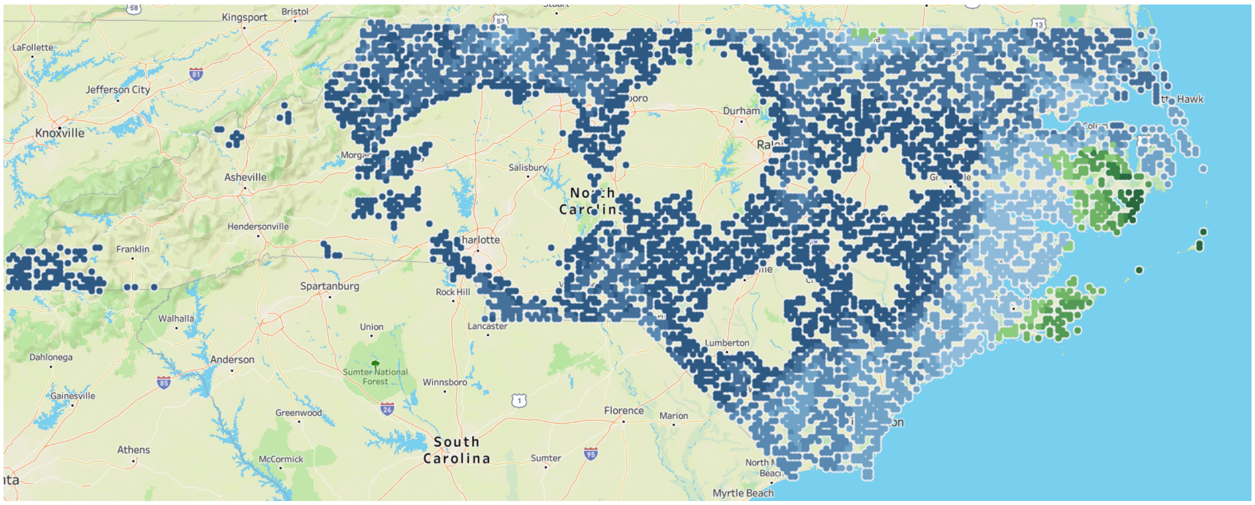

Figure 3. TVWS Spectrum Availability in North Carolina. See https://go.ncsu.edu/tvws-map

Due to Hyde County's extremely low population density, commercial internet service is a challenge for providers. One of our research goals was to determine if we could work with a local commercial service provider to "seed" the market with TVWS in student homes. The premise being that, by ensuring that a baseline number of families would receive funding for equipment and service for at least one year, the local provider would have the ability to leverage these locations as the starting point for a broader commercial wireless offering. We worked with RiverStreet Networks, which had acquired North Carolina Wireless LLC., a Wireless Internet Service Provider (WISP), located in Hickory, NC.

We worked with RiverStreet Networks and Hyde County Schools to identify locations, families in need of access, and technology to test. In this pilot, RiverStreet Networks procured the hardware from 6Harmonics and handled all the details and implementation of building the base stations, finding backhaul and sending installation technicians to homes to install the devices.

TVWS is just one component of the total solution RiverStreet Networks will likely require to completely solve the broadband challenges in Hyde County. In general, the higher the frequency (and thus the higher the bandwidth) of a signal, the more data can be carried by the signal. But higher frequency signals are generally more impacted by obstructions such as trees, walls and even the atmosphere. This is why TVWS may serve as an important piece in the rural broadband puzzle. TVWS will likely be used only to reach the most distant locations from a multi-band tower. Higher frequency technologies, like LTE and Wi-Fi might be better suited for near-in customers. TVWS can share a tower with these technologies and add a dozen or more "extra" long distance customers, improving the deployment cost per customer, thus improving the likelihood of economic viability of the rural service provider.

This multi-layered approach using a portfolio of spectrum, products, and techniques is key to maximizing coverage from a given tower. Towers, and their associated fiber backhaul, are often one of the most expensive recurring costs for WISPs. Thus, we are hopeful that adding TVWS to the portfolio, and seeding the market with the first thirty K-12 families, will enable RiverStreet Networks to not only connect all K-12 students, but open up commercial service to businesses, farmers and other families throughout the county. We also are hopeful that RiverStreet Networks will be able to offer an educational tier service that is affordable to K-12 families and leverages FCC subsidies like USF Lifeline and the FCC Emergency Broadband Fund (EBB).

As of June 2021, RiverStreet Networks has deployed a quad-radio base station on a water tower in Engelhard. The abundance of TVWS spectrum makes this an ideal test location. Twenty-one K-12 families have had customer premise equipment (CPE) professionally installed. Many of the students in these families are receiving home internet for the first time in their lives. There are many parts of Hyde County where cellular service will not work or is not reliable enough to complete a call.

Figure 4. TVWS customer premises equipment installed near Engelhard, NC. Source: RiverStreet Networks)

The total aggregate capacity of each of the four TVWS radios on the water tower is about 75 Mbps. This yields about 300 Mbps which will be shared across 30 CPE, for both downstream and upstream. Per user throughput has ranged from 5 Mbps to 45 Mbps, but we do not have enough sample data to draw any conclusions at this time. Reliability of the service seems good at this point, but more testing is needed.

RiverStreet Networks and 6Harmonics have been working to fine tune the network, upgrade firmware, and increase capabilities. The lack of local resources with radio frequency (RF) skills has been a growing pain, but we are confident that we will collect statistically significant speed test data during the summer and into the fall, once the buildout is complete.

The low marginal cost to add more users on TVWS, and the reach of the signal (up to 5 miles) provide solid reasons to continue the pilot. Additionally, as stated previously, RiverStreet Networks may reach other students, closer to the towers, with other less expensive technologies, thus lowering the total cost per user further. At this point we recommend building on the momentum already in place in Hyde County and continue this pilot through the 2021-2022 school year. Without the complete dedication of Superintendent Basnight and his staff this project would not have been possible in Hyde County.

Ocracoke Island

The TVWS project was limited to the mainland of Hyde County because there did not appear to be any reasonable way to obtain fiber backhaul that would be needed for base stations on Ocracoke Island. While we do not have firsthand knowledge, we believe there is only a single fiber optic cable connecting Ocracoke to Dare County and then the mainland. That cable is controlled by a service provider that has not been motivated to improve broadband capabilities on the island for many years, and we did not think backhaul would be easily obtained or affordable. Instead, we decided to test SpaceX Starlink service exclusively on Ocracoke and focus on TVWS only on the mainland.

Citizen Broadband Radio Service (CBRS)

Over the last decade, the FCC in conjunction with the federal government (especially the Department of Defense) has identified frequency bands that have been historically underutilized, and that could be repurposed for more modern commercial broadband uses. One such band in the 3.5 GHz range had been reserved for many years for use by the Navy for ship-based radar systems. Since there are no Navy vessels located on land, this band was largely available across the continental United States.

The FCC decided to create the Citizens Broadband Radio Service (CBRS) and open 150 MHz of bandwidth in the 3.5GHz range with a three-tier licensing paradigm. The first priority user of this band is the Navy, with ultimate authority to use the band as needed. Secondary licenses, called Priority Access Licenses (PAL), for up to half of the spectrum were auctioned off by the FCC on a per-county basis, in 10 MHz swaths. For a list of auction winners see the FCC website. Finally, the remaining spectrum is available under a General Authorized Access (GAA) license. Both PAL and GAA license holders must configure their devices to "check-in" with a Spectrum Access Server (SAS) about every 10 minutes. The SAS ensures fair use of the spectrum with priority given to the military and the PAL holders. It coordinates the spectrum such that radios near each other have their frequency and power set to minimize interference and maximize performance. This sort of dynamic spectrum sharing will likely be a cornerstone of many future frequency band modernizations. Spectrum is a scarce resource, and the FCC is working to find ways to maximize use. Our CBRS pilot will utilize the GAA license; in other words no funding was required to access the spectrum.

CBRS closely resembles cellular LTE technology. At 3.5 GHz, CBRS has higher capacity than TVWS, but generally lower propagation distance. Thus TVWS is more appropriate in very low population density locations while CBRS is more appropriate in higher density locations where the users will be within a mile of the CBRS tower or base station. So called "small cell" CBRS radios could also be used in dense urban environments, for example using street lights or telephone poles spaced several hundred feet apart to create a high-density Private LTE network. CBRS might also be very useful in high-capacity sports venues, hospitals, and education campuses.

Status of Pilot in Chatham County

Chatham County was selected for the CBRS pilot for a number of reasons. First, the NC Broadband Infrastructure Office data indicates a very large number of Chatham County residents do not have home internet access. Secondly, the location of Siler City, being only an hour drive from NCSU campus was deemed important as this pilot will require more "hands on" work to complete. We also hope to draw on experience from the state's K-12 internet backbone provider, the non-profit MCNC, based in Research Triangle Park. MCNC has substantial knowledge related to the complex networking architecture that may be required to securely connect the CBRS system to the internet and ensure Chatham County Schools has complete control over the traffic passing through the network. Finally, we identified an area in Chatham County with a large population of students who lack home internet. Depending on the performance of the products, the area that can be covered by the system may become larger over time. Once the architecture is proven, other technologies might also be added to the tower to expand the coverage area.

Of all the pilots, the CBRS pilot in Chatham is technically the most complex and thus has taken the longest to design. No hardware has been installed permanently for this project yet, but the base station radio vendor has been tested by the Friday Institute. Additionally, client devices, or customer premise equipment (CPE) that will work with the base station have been selected. Chatham County government, in cooperation with Chatham County Schools, have been excellent and willing partners in making this pilot a success. The County has offered a mounting point on one of their towers which is within a mile of a number of students lacking home internet access. The goal of the pilot will be to place CBRS CPE in approximately 30 students' homes, spread across three mobile home communities in Siler City. Mobile homes, which sometimes can have significant metal construction, will prove a challenging test for the selected products. Backhaul is also available at the tower, and we plan to connect the CBRS radio into a secured portion of Chatham County School's network to provide firewall and filtering capabilities.

Private LTE (PLTE)

The most interesting aspect of CBRS is that it enables virtually any entity to stand up and run a private LTE network, without having to pay a service provider a monthly fee or purchase spectrum. CBRS-based private LTE enables entities to take advantage of the low-latency, high-throughput capacity of LTE using a deployment model more like Wi-Fi. Like LTE, client devices have SIM cards that are used to authenticate users. The SIM cards are tied to the PLTE network and ensure that only authorized users gain access to the network. Unlike commercial LTE though, the day-to-day management of the network is provided by the owner, in our case the school district. This is very similar to the Wi-Fi network model used in schools, but now the network is extended out to the student home. This model brings with it unique opportunities and unique challenges.

One of the advantages of CBRS-based PLTE, and the reason this pilot in particular was developed, is that there is no "middleman" in the network. Chatham County Schools will own all of the equipment outright. There is no monthly service fee, and the capacity is limited only by the number of radios and spectrum available. While there are ongoing costs, like backhaul and software licenses, there is no monthly "service fee" as with traditional cellular service.

We selected base station radios from Celona (https://www.celona.io) because they offer Wi-Fi-like management for CBRS-based PLTE. Celona is well positioned to deliver radios and a user experience similar to that which school technology staff already expect when managing the school Wi-Fi network. For the CPE devices, we selected CradlePoint because Chatham County Schools already uses CradlePoint routers for their bus Wi-Fi program and thus has experience using the products and management platform. Minimizing the learning curve and maximizing reuse in the LEA was a key goal to help ensure success.

Despite the optimism we have for PLTE, it must be tempered with reality. In most LEAs, school technology staff are already overwhelmed with work just to keep the school networks up and ensure digital resources are available in the school building. Adding the complexity of managing an outside-of-the-school network without additional resources is not realistic and could be a recipe for disaster. Several commercial service providers are actively managing CBRS-based PLTE, but the basic premise of PLTE is that there is no monthly recurring cost for the network. In reality, every infrastructure has a monthly cost, whether it is an internal cost or paid to a third party; no network is free.

There is also concern that a school district creating a K-12-only PLTE network will effectively hamper broadband deployment. While K-12 students might have excellent, "free" home internet service, their older neighbors without students at home would not. Since commercial service providers will prioritize new buildout based on market opportunity, neighborhoods with PLTE provided by the school district might be deprioritized. On the other hand, if only economically disadvantaged students that cannot afford commercial service are provided with PLTE connections, the net opportunity loss to the commercial providers is effectively zero. Realistically, a better approach will likely involve some combination of the school district working with commercial service providers and the broader community to ensure all residents in the county have coverage.

Segmenting the market opportunity does not encourage private investment. However, if no investment has been made in a community, the community should have the ability to connect its students. There is no easy solution to this problem. We see a significant opportunity for public-private partnerships with PLTE. At this point in time, if a home does not have internet access, it likely never will unless a subsidy is involved in some fashion. Government will be involved in one form or another in order to connect every student in the state.

Next Steps in Chatham County

The pilot will (hopefully) begin this summer with an initial fifteen CPE and one base station radio. If this initial tranche goes as planned, we will acquire an additional 15 CPE units. Under normal circumstances, a tower would not be used for a mere 30 clients; however, current funding available only allows for purchasing about 30 CPE. Our initial cost model with only 30 clients shows that it does not make economic sense to deploy PLTE on CBRS at this density. Our final report will extrapolate the cost to determine the density at which CBRS PLTE does make economic sense. Over the coming months we will also investigate communities, like Tucson, Arizona and the Utah Education and Telehealth Network, which have deployed their own wide scale CBRS-based PLTE networks.

Initial Findings

While the DPI grant specifies this initial report is due June 30, 2021, we are reluctant to draw many conclusions at this time. Due to the pandemic, the pace at which some work items could be completed was hindered and we will be producing a follow up report in the first quarter of 2022.

We have found that there is no single solution that can or will solve the challenges of rural broadband. These three wireless technologies can serve as components to the solution, but no single technology can provide access to every student in NC.

Starlink Low Earth Orbit Satellite Internet

In general, Starlink provides high-capacity, low-latency internet access for the most difficult to reach locations. The only requirement is an unobstructed view of the sky; virtually any location in the United States will eventually have access to Starlink service. However, Starlink is fairly expensive and likely not affordable to a significant portion of the rural population currently lacking internet access. While there are issues with the service occasionally going out for a minute or two a few times per day, we believe this issue will be rectified once more satellites are launched throughout 2021.

Our test data shows many Starlink users in the pilot program received over 100 Mbps downstream throughput. The top documented downstream speed test in our data is 272 Mbps with the range of properly installed user terminals being generally in the 50 to 150 Mbps range. We have noted that slower speeds and much more frequent outages are reported by users that have heavily wooded yards and cannot obtain an unobstructed view of the sky. We have provided funding for roof mounts to be purchased from SpaceX and hope to see improvements in these sites this summer.

Upstream throughput, from the student home to the internet, has generally ranged between 15 and 40 Mbps with a highest recorded upstream speed at 48 Mbps. Upstream throughput was particularly important for remote learning during the pandemic as this is the key parameter that dictates if a student will be able to send their video stream ***to*** the teacher.

The final metric we studied in the speed test is latency, the time it takes data to traverse from the student home to the internet and back. In traditional geosynchronous satellite internet services, latency is often over 600 milliseconds. This high latency causes live audio or video conversations to be very awkward, often with people talking over each other since it may take an entire second before people realize that another person is talking. Since Starlink satellites are so low to the Earth's surface, the latency is much lower, more in line with cable modem service latency. In fact, we have seen many cellular LTE services with higher latency than Starlink. The latency for Starlink in our test sample is generally 40 to 60 milliseconds, with jitter (the variation in latency) usually less than 20 microseconds.

Starlink is significantly easier to deploy and set up at student homes as compared to the other two technologies under study in our research. Starlink user terminals, commonly referred to as "Dishy", were distributed by school district staff based on need and other functional parameters specified by SpaceX. Each unit includes an antenna (a 23-inch diameter dish) that must be located outside with a clear view of the sky. An Ethernet cable runs from the dish into the house where a small home router provides Wi-Fi to the client devices. Each family uses the Starlink smartphone app to set up the dish and Wi-Fi, including the Wi-Fi password and other parameters. Many families were able to install the units and get them working in an hour or less. Finding a location with a clear view of the sky is vitally important. The Starlink app uses an augmented reality feature to allow the user to locate appropriate positions for the dish on their property.

Figure 5. Starlink customer premises equipment installed on Ocracoke Island, NC.
Left: Outdoor antenna. Right: Indoor Wi-Fi router. (Source: Hyde County Schools)

Starlink does not have a data cap, which is a key differentiator between it and GSO offerings like HughesNet and ViaSat. Many families that have GSO service reported that during the pandemic they consumed their entire data allowance in the first week or two of each billing cycle, effectively rendering the service unusable for the second half of the month. We think it is important that Starlink continue to offer service with no data cap, but it would be advantageous to many North Carolina families with K-12 students if a lower priced service were offered. If a lower speed "educational only" service (e.g., 25 Mbps symmetric) could be offered in the $40 per month range, many more families in North Carolina could take advantage of it. Other quality of service schemes (such as deprioritizing non-educational traffic to high-volume services like

Netflix and HBO Max) could also be used by SpaceX to make the service more affordable to K-12 families while not impacting full-paid subscription customers.

Starlink Outages

We have noted that some users find the service to work well, but with occasional (a few times a day) brief outages of a few minutes. We believe these outages are a function of the limited number of satellites that have been launched by SpaceX thus far. Until the entire constellation is launched, there will be occasional windows where no LEO satellite is overhead and visible to the user terminal. In these brief windows, no internet access is available. We are hopeful that these windows will diminish to zero over the next year.

In addition to these occasional outages, for a small number of users, we have received reports of the Starlink service going out for a minute about every 10 minutes or so. We believe these service disruptions are caused by improper user terminal placement, resulting in an obstructed view of the sky through foliage or buildings. The Starlink signal is in the tens of gigahertz frequency range and as such it will not penetrate trees, leaves, or walls. We hope that school staff can provide roof mounts and work with parents this summer to resolve these issues.

Starlink's Role in Rural North Carolina

There is no magical solution for the rural internet challenge. To connect every student in North Carolina, a portfolio of technologies will be needed. Once SpaceX completes the launch of their LEO constellation, there will be virtually no location in NC that cannot be served by Starlink. That does not mean that Starlink is the answer everywhere; in fact, the opposite is true. Starlink should be the answer *everywhere there is no other option*. As amazing as Starlink is, the constellation can only support a finite number of users. **We should work to ensure those students with absolutely no other option for service are the ones using Starlink**. Starlink is $99 per month, which is not affordable to many families. There are other technologies that may be more affordable, especially in more populated areas. However, we strongly believe Starlink will play a vital role in connecting the hardest to reach students in North Carolina. Starlink will be an invaluable tool in our portfolio to level the playing field for all students in North Carolina.

Broadband Infrastructure Office Satellite Grant

The General Assembly and the Broadband Infrastructure Office have already taken steps to create a grant program specifically for LEO internet service. Given that there are tens of thousands of homes that will not be connected by fiber for many years, the expansion of this grant program may be warranted. Additionally, new competitors may enter the LEO and MEO marketplace in the next few years, making satellite more competitive. We believe traditional GSO-based satellite internet will remain viable only for industrial use, for applications like payment processing, infrastructure monitoring, and other uses where low bitrate, high latency data is required in the farthest reaches of the Earth.

Television Whitespace (TVWS)

RiverStreet Networks, a commercial provider in North Carolina, is continuing their testing of the TVWS equipment deployed to students on the mainland of Hyde County. We believe this technology could become a useful component in the portfolio of technologies available to Wireless Internet Service Providers (WISPs), in very low-density environments, especially east of Interstate 95. While the throughput is lower than fiber, or Starlink, the cost is also lower once economies of scale are reached. Current products are still early in their life cycle and as volumes increase and more technicians become competent with these products, the cost to deliver TVWS-based internet access should be reduced.

Due to its low frequency, TVWS is particularly useful in areas where foliage obstructs the view to the tower. However, with the lower frequency comes lower total bandwidth and thus lower throughput. More than likely, TVWS will be added as the "top" antenna on WISP towers to reach only the farthest out, or most foliage-covered customers. Other technologies such as LTE (CBRS, both licensed and unlicensed), and Wi-Fi (unlicensed 5 GHz) may be more cost effective in reaching customers located closer to the tower. Nonetheless, the addition of TVWS to augment towers for a handful of hard-to-reach customers could significantly improve the business case for investment in more rural locations. It remains to be seen if RiverStreet Networks, or any for-profit WISP, can create a workable business model in extremely low-density locations like the mainland of Hyde County.

Performance data for the TVWS users is limited. We hope to collect statistically significant samples over the summer. To date, twenty-one families have had their TVWS customer premises equipment installed and are using it. In mid-July an additional nine families will receive TVWS equipment.

There have been challenges with the deployment of TVWS in Hyde County. The technology requires a professional installation, which means coordinating a technician with a parent. This has been extremely difficult during the pandemic. Furthermore, the overwhelming amount of spam calls for car warranties and credit scams being made to people in North Carolina has rendered the phone system useless. People simply no longer answer unknown callers, and they certainly will not call back to someone offering to connect them to the internet for "free".

We are optimistic that TVWS technology can be a component in a broader solution to rural broadband, especially in lower population density locations and when coupled with other wireless technologies commonly used by WISPs.

Citizens Broadband Radio Service (CBRS)

The third technology we are evaluating is school-managed CBRS-based Private LTE (PLTE). While we do believe that CBRS will be a component of the broadband solution, especially in more urban areas, it is unclear if school-managed PLTE will be scalable. Initial indications show that selecting only students as recipients of service and expecting a K-12 district to manage what is effectively a wide area network may not scale. Targeting only a subset of the population for use of a specific frequency band may not be the most efficient use of spectrum.

School technology staff is oftentimes already overburdened just with the normal operation of the school networks. Adding the complexity of supporting off-campus users could push technology departments beyond their limits. While we will continue to work on the CBRS pilot for this research, at this time we would not recommend a school-owned PLTE network be deployed in North Carolina. Rather, a better solution will likely consist of a public-private partnership or a broader cooperation between school, county and other government agencies, with the assistance of commercial operators. If a district or community is committed to a PLTE offering to serve students, the focus should be in higher density locations where the economies of scale are conducive. The promise of PLTE is that users need not pay a monthly service fee, however, the realities are such that the ongoing cost to run and maintain the network are not trivial. It is unlikely that an exclusively K-12 PLTE network will be cost effective in NC.

PLTE will likely make economic sense in university campus environments, or in other locations with higher density populations when an entity (e.g. county housing authority) has right of way and is motivated to provide low-cost and finely controlled access to their campus network.

Wireless and Networking Skills Gap in North Carolina

One of the challenges to completing this pilot program, particularly the TVWS and CBRS components, is the difficulty in finding talented staff with radio frequency (RF) and networking skills in rural communities. Oftentimes service providers must send resources from across the state rather than rely on local employees in rural areas.

DPI and the State Board of Education should consider developing a program to encourage middle and high school students to take an interest in RF and networking. The amateur radio community may be a great partner in such a program. Amateur radio clubs at high schools, for example, could serve as inexpensive ways to teach students practical knowledge about radio while also offering those students with a deeper interest the opportunity to tackle more advanced topics aligned with college engineering programs. The Friday Institute, the NCSU College of Engineering, and NCSU Extension would also be excellent partners in this sort of endeavor.

Recommendations and Future Work

At the onset of this project, one of the top goals was to maximize the amount of infrastructure, equipment, and knowledge that would remain in place after the research is complete. We did not want to spend hundreds of thousands of dollars and not at least provide a starting point for a sustainable internet service for the participating school districts. Given the initial investment and work that has already been completed we do think it would be valuable for DPI to fund a second year of the pilot, which includes a full school year. Since the bulk of the equipment is already purchased, we anticipate the cost for a second year of service, for all students in the DPI-funded portion of the pilot program to be $75,000. If DPI also wanted to fund a second year for the DIT-supported Starlink connected students, an additional $130,000 would be needed.

For the second year of service, if funded, we suggest that DPI allocate the funding via PRC rather than directing it to the Friday Institute as a research grant. This would ensure that the maximum amount of funding goes directly to pay for the internet service for these students. Since the tools and instrumentation are already in place, the cost of the second year of the research would be de minimis.

While there is a broad effort in policy and COVID recovery legislation to bias the solution towards fiber, we believe that wireless solutions will remain an important component to the total solution for North Carolina. It might take decades to install fiber to the far corners of North Carolina; our students cannot wait for that.

The Friday Institute will produce a follow-up to this report in the first quarter of 2022 with much more quantitative data. Now that the projects are becoming more operational and built out, much more data should be available in the 2021-2022 school year.

Appendix A. Educational Broadband Service (EBS)

*The Friday Institute has been researching Educational Broadband Service (EBS) since 2017 and closely following the FCC proceedings related to it. Unfortunately, there was no way to include this technology in the pilot program. We mention EBS in this report because it **may** represent a potentially untapped resource in the effort to deploy broadband to students ubiquitously across the state.*

Across North Carolina there are about 70 spectrum licenses held by public education institutions in the Educational Broadband Service band. This band, at 2.5 GHz, was allocated to education institutions decades ago. The economic feasibility of using this band has increased drastically over time as technology has progressed. Now, virtually all of these licenses are leased to Sprint/T-Mobile, which is using them to provide commercial LTE service in many urban locations. Due to recent changes in FCC regulations governing this band, private companies are now free to purchase these licenses outright from education institutions.

While the EBS band has never met the goals originally intended by the FCC, we are now at a juncture where the State of North Carolina should either decide to consider maximizing the use of this band for education, or let it go to the private sector for commercialization. Of the approximately 70 licenses in North Carolina, about 30 are owned by the UNC System, 30 are owned by individual community colleges and a handful by LEAs. These licenses generate a small amount of lease revenue for their holders, but if their use was coordinated at the statewide level, the licenses could be a very valuable asset to the state.

As the current leases begin to expire, we expect many license holders will be approached to sell their license. We are not aware of any current law in North Carolina that would prevent this. We view spectrum licenses much like real estate. No new spectrum will ever be created; it is a fixed asset that will only rise in value over time. To this end, we recommend the General Assembly enact legislation that would require the sale of spectrum by a public entity to follow a similar procedure as the disposition of real estate. Currently, under NCGS § 146-29, the sale of real estate by a state entity must be approved by the Governor and the Council of State. Given that an individual spectrum license in the 2.5 GHz band is virtually useless to a single school or college, the perceived value of the spectrum is likely far less than the actual commercial value, when the licenses are used over a much larger area in a coordinated fashion. For this reason, we believe the General Assembly should act immediately to ensure the spectrum is retained, and then consolidate the licenses into a bloc, either for an improved negotiating position or to create an education focused network public-private partnership.

The Friday Institute would be delighted to provide an executive overview of EBS to the State Board of Education, the General Assembly or any other policymakers that are concerned with spectrum policy in North Carolina. EBS licenses generally cover an area with a 35-mile radius from the institution, each with about 20 MHz of spectrum. An interactive map of the EBS licenses in North Carolina can be found here: https://go.ncsu.edu/ebsmap

Appendix B. Student Safety

As a requirement of this research program, pilot LEAs agreed to ensure that all student devices had content filters which meet the requirements of the Child Internet Protection Act (CIPA) as well the LEA's content filtering policies.

Out of an abundance of caution, the Friday Institute procured one year of VIP access to SmartSocial (https://smartsocial.com), an online resource that provides the following:

- Keeps parents informed of how to monitor student internet use
- Updates parents on the latest apps and techniques students are using
- Teaches parents how to direct student online behavior in a positive manner
- Teaches students how to use social media to promote themselves in the most positive light for future colleges and employers

Any parent that has received internet access as a part of this pilot program in any of the four pilot LEAs can obtain a VIP account on SmartSocial by contacting the Friday Institute or their LEA technical staff. Additionally, any teacher in any of the four pilot LEAs may also obtain access to the resources.

While the internet is an invaluable resource, we must continue to teach good digital citizenship and prevent cyberbullying and screen addiction.

Appendix C. Budget and Financial Discussion

The table below provides the budget for both the DPI and the BIO grants. While this report is required by the DPI grant, we provide the BIO data for completeness as it leverages much of the work already being done for DPI. The BIO funding has enabled the LEO research to encompass a much larger population for study and has enabled us to understand the operational characteristics of LEO satellite internet more quickly.

DPI	LEA	Technology	Budget	Target Number of Families	
	Hyde	TVWS	$69,355	30	
	Swain	LEO	$69,355	30	
	Chatham	CBRS	$69,355	25	
	Total Subawards		$208,066		
	FI Staff and Travel		$41,934		
	Total DPI Funding		**$250,000**		
BIO	**LEA**	**Technology**	**Budget**	**Target Number of Families**	
	Hyde	LEO	$102,120	45	
	Swain	LEO	$75,610	30	
	TBD	LEO	$75,610	30	
	Total Subawards		$253,340		
	FI Staff		$10,660		
	Total BIO Funding		**$264,000**		

* All data is budgetary. As of 6/14/21 all three subawards from the DPI grant have been executed. As of 6/14/21 the BIO grant subawards have been completed to Hyde and Swain, but we are still working with a third LEA to ensure 30 families meeting the technical requirements can be identified. Any unencumbered funds from the FI Staff line items, as of the end of CY 2021 will be distributed to the LEAs to provide support for ongoing service costs for the second year of service.

It is the intent of the Friday Institute to minimize the staff time required for this project and to maximize the funding that goes to the LEAs so that they may procure services and equipment for the research. By issuing sub-awards rather than having the University buy and track equipment, we were able to much more quickly and nimbly acquire products and begin testing. As the bulk of the work at the FI is being completed this calendar year, apart from the final report and monthly testing, it is possible that the second year of the project would require no additional FI staff support and no new equipment expenses. Only the monthly service cost of approximately $200,000 would be required to keep all families in the pilot program connected for a second year as we conduct additional testing. We do not anticipate a need for a third year of research; however, as new technologies emerge, this well-established pilot program and the goodwill created with the LEAs may prove to be a useful testbed for other products.