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Wireless Innovation for Last Mile Access: An Analysis of Cases and Business Strategies[1]

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EXECUTIVE SUMMARY

Broadband Internet access has become crucial to many aspects of life. Internet access and Internet-related skills have transformed the way individuals communicate, how they acquire knowledge, and their means of market participation. Internet access has become necessary for individuals, localities, and countries to remain competitive and has fostered both local and nationwide development.

However, in many parts of the globe, the lack of access creates digital inequalities that can advantage certain groups relative to others. Moreover, in the U.S., private entities have decided that it is unprofitable to expand their high-speed, wireline Internet broadband networks to certain regions—for instance, to highly rural parts of the country or economically distressed urban neighborhoods.

In this case-based analysis of business strategies, as well as the accompanying regulatory analysis, we explore an alternative means for broadband expansion: wireless broadband. Although at present, wireless cannot provide anywhere close to the potential capacity available from advanced fiber networks, it has many other advantages. First, and perhaps foremost, wireless alternatives may be the only economically feasible means of broadband expansion to certain parts of the country. Although they cannot provide capacity that is measurable in terabits per second, as fiber networks can, wireless technologies—depending on the frequencies used and other factors—can suffice for many modern applications: information acquisition for job search, health, and other needs; distance learning; and even video streaming. Second, wireless broadband can permit mobility, something that wireline networks are not designed to provide. Third, the performance of last mile wireless links is partly dependent on the backhaul capacity to which it is connected. So, as fiber extends closer to end users, it enhances the speed and reliability of the wireless connections it supports. Finally, wireless networks can be deployed more rapidly than wireline networks, so that even if there are plans for higher capacity, wireline deployment in the future, wireless can meet more urgent needs.

In this report we examine a dozen cases that provide real world evidence and strategic insight related to both the advantages and challenges involved in deploying wireless in scenarios spanning a range of densities and topographies, spectrum, applications and the institutions and stakeholders involved in and impacted by the network deployments.

The first five cases examined in the report focus on the use of wireless communications to better connect and better serve students. The first three of these, which include one case study and two additional examples, focus on improving connectivity for students lacking affordable (or, in some cases, any) broadband access at home. This is followed by a case study focused on linking remote campuses with gigabit-speed connections, and an example in which a university uses wireless backhaul to support Wi-Fi hotspots at campus transit stops.

We then examine five cases involving the use of wireless by Community Anchor Institutions (CAIs) and municipalities to extend and enhance their services. These include one case study and four additional examples covering a range of applications, including support for public hotspots, video surveillance, remote sensor-based monitoring, community service-focused apps, emergency communications, and telemedicine.

Our final two case studies focus on situations in which privately owned ISPs use wireless to improve Internet access in the communities they serve. The first focuses on a rural service area that includes very remote locations and challenging terrain and weather. The second focuses on an urban area that includes relatively dense concentrations of multiple dwelling units and office buildings.

Based on the content of the cases it examines, each of these case-focused sections of the report concludes with a review of general lessons and insights derived from these cases. This is followed by a discussion of each section's implications for the nation's Research and Education Networks (RENs), whose fiber networks may be especially well suited to provide high-capacity backhaul for cost-effective wireless connections.

The final section of this report discusses several key themes that have emerged from our research and analysis of cases. These include:

- Both Educational Broadband Service (EBS) and Television White Space (TVWS) spectrum have unique potential to help bridge remaining gaps in last mile access, especially in the nation's smaller markets and rural areas. At the same time, each of these spectrum bands faces a mix of technical limitations, regulatory uncertainty and geographic variability that impacts the extent to which that potential can be realized—in the nation as a whole, and in particular local situations. In light of this, we see value in continued tracking and analysis of technical and regulatory trends and network deployments related to these two spectrum bands, as well as in-depth analysis of their geographic availability in relation to the nation's unmet connectivity needs.

- Millimeter waves (mmW) can provide quickly deployable and relatively inexpensive gigabit-speed wireless links, but are notably vulnerable to rain-induced signal loss. As a result, their application is limited mainly to relatively short (e.g., < 1 mile) line-of-sight links, making them most useful in urban areas containing fairly high concentrations of multiple dwelling units (MDUs) and office buildings. In such markets, mmW links can serve as a strategic and opportunistic complement to an urban fiber connectivity strategy, by enabling a service provider to quickly connect an MDU or office building with gigabit wireless. Then, if and when that building's demand is sufficient to cost-justify an upgrade to fiber, the mmW link can be relocated to serve another building whose ability to cost-justify fiber connectivity is less clear.

- Given the economic and other challenges associated with bridging our nation's remaining gaps in broadband access and the benefits it provides, locally-anchored enterprises and business models focused on sustainably addressing local needs may be better suited to this task than enterprises and business models focused on maximizing investor returns in national or global markets. Virtually all of the cases examined in this report embody some institutional and business case elements reflecting this prioritization of community benefits versus shareholder returns.

INTRODUCTION

This report examines innovative approaches that utilize wireless communication technologies to address the need for broadband Internet connectivity in difficult to reach or otherwise underserved locations. A key focus of the report is how wireless extensions of fiber networks, such as those operated by Research and Education Networks (RENs), can help to more fully achieve the goal of universal broadband access in operationally feasible, cost effective and sustainable ways. Toward that end, the report: (i) examines a dozen real world use cases that highlight key factors related to using wireless technologies to expand connectivity across a range of application areas and physical, economic and institutional contexts; (ii) extracts insights and lessons from these cases to inform public policy and network initiatives aimed at expanding Internet connectivity and its benefits more quickly and more fully.

Our selection of cases and our analysis focuses mainly on projects involving community anchor institutions (CAIs) with a public service mission, including K-12 and higher education institutions, libraries, local governments and private non-profits. It also includes two case studies focused on commercial Internet Service Providers (ISPs) that have used innovative wireless solutions, often in partnership with CAIs, to expand access, speeds and consumer choice in the communities they serve.

The report is anchored in interviews with approximately 30 individuals involved in and knowledgeable about wireless deployments and technology developments. Together, the cases reviewed in this report encompass a range of spectrum bands, population densities, topographies, social and economic goals, business models, organizational structures and alliances, stages of project implementation, degrees of success, and hurdles faced and overcome.

Based on these interviews and related research and discussion, the project team has focused on five case studies as most relevant and informative, and therefore worthy of in-depth analysis. The report also includes less in-depth discussion of seven example cases that supplement the scenarios exemplified by and lessons learned from the five primary cases. The bulk of this report is devoted to an examination of these twelve cases, structured in sections by the types of connectivity need they aim to address. At the end of each section, and of the report as a whole, we consider lessons, insights and themes that emerge from our analysis of these cases.

THE PROBLEM AND THE OPPORTUNITY

As U.S. and global economic, social, political and public service systems become ever more deeply anchored in and dependent on Internet-based communications, there is a growing sense among policymakers and citizens that more must be done to address the "digital divides" and "homework gaps" that, as this shift to online interactions broadens and accelerates, are amplifying existing divides related to geography and income (e.g., in education and economic opportunity).

In terms of geography, the FCC's 2016 Broadband Progress Report notes that:

- 39 percent of rural Americans (23 million people) . . . and 68 percent living in rural areas of Tribal lands (1.3 million people) . . . lack access to 25 Mbps/3 Mbps . . . In contrast, only 4 percent of urban Americans lack access to 25 Mbps/3 Mbps broadband.
- 20 percent of rural Americans lack access even to service at 4 Mbps/1 Mbps, down only 1 percent from 2011, and 31 percent lack access to 10 Mbps/1 Mbps, down only 4 percent from 2011.[2]

As for income-related digital divides, a Pew Research Center analysis of 2013 U.S. Census Bureau American Community Survey data found that:

- Roughly one-third (31.4 percent) of households whose incomes fall below $50,000 and with children ages 6 to 17 do not have a high-speed internet connection at home. This low-income group makes up about 40 percent of all families with school-age children in the United States, according to the bureau's American Community Survey (ACS).[3]

The Pew analysis also found that the percentage of households with children ages 6 to 17 lacking a high-speed home Internet connection increased to nearly 40 percent for those with annual income below $25,000, versus just 8 percent for those with incomes above $50,000.[4] In some U.S. cities, the numbers are even worse than suggested by national averages. For example, according to a recent analysis of 2015 ACS data by Connect Your Community 2.0, only 52 percent of Cleveland households and just 46 percent of Detroit households had "fixed broadband" Internet connections in 2015.[5]

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[2] Federal Communications Commission. 2016 Broadband Progress Report. www.fcc.gov. ("2016 Broadband Progress Report") Available at https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2016-broadband-progress-report.

[3] Horrigan, J. (2015, Apr. 20), "The numbers behind the broadband 'homework gap'" Pew Research Center. Available at http://www.pewresearch.org/fact-tank/2015/04/20/the-numbers-behind-the-broadband-homework-gap/.

[4] Ibid.

[5] Connect Your Community (2016, Sep. 19). "2015 Census: 'Fixed broadband' in only half of Cleveland, Detroit households," Connect Your Community 2.0. Available a http://connectyourcommunity.org/new-census-fixed-broadband-in-only-half-of-cleveland-detroit-households/.

In terms of connecting schools, the FCC's 2016 progress report found that "while an increasing number of schools have high-speed connections, approximately 41 percent of schools, representing 47 percent of the nation's students, lack the connectivity to meet the Commission's short-term goal of 100 Mbps per 1,000 students/staff."[6]

In the face of these challenges, federal policies and funding programs are being developed and revised to help address the nation's digital divides. These include relatively recent revisions of the FCC's Connect America Fund (CAF),[7] Lifeline[8] and E-Rate[9] programs, as well as other Commission initiatives, including its Rural Health Care Program, which aims to improve rural healthcare by upgrading the level of broadband access available to rural healthcare providers and the communities they serve.[10] The US Department of Agriculture's (USDA) Rural Utility Service (RUS) unit also has a number of loan and other support programs designed to support connectivity in rural areas.[11]

Perhaps the current federal government initiative with the broadest scope is ConnectALL, which was announced on March 9, 2016 by the Obama administration.[12] Among its goals is to bring together and build on the progress made by existing government agencies and programs, private sector companies, non-profits, foundations and the research community, as well as existing White House initiatives such as ConnectEd,[13] which is focused on connecting schools and libraries, and ConnectHome,[14] whose focus is improving connectivity in public housing.

Another important initiative aimed at expanding broadband access and adoption was the broadband-focused component of the American Recovery and Reinvestment Act of

[6] 2016 Broadband Progress Report.

[7] Federal Communications Commission. Connect America Fund (CAF). www.fcc.gov. Available at https://www.fcc.gov/general/connect-america-fund-caf.

[8] Federal Communications Commission. FCC Releases Lifeline Reform and Modernization Item. www.fcc.gov. Available at https://www.fcc.gov/document/fcc-releases-lifeline-reform-and-modernization-item.

[9] Federal Communications Commission. Universal Service Program for Schools and Libraries (E-Rate). www.fcc.gov. Available at https://www.fcc.gov/general/universal-service-program-schools-and-libraries-e-rate.

[10] Federal Communications Commission. Rural Health Care Program. www.fcc.gov. Available at https://www.fcc.gov/general/rural-health-care-program.

[11] United States Department of Agriculture. Rural Development. Telecom Programs. www.rd.usda.gov. Available at http://www.rd.usda.gov/programs-services/all-programs/telecom-programs.

[12] The White House. Office of the Press Secretary. FACT SHEET: President Obama Announces ConnectALL Initiative. www.whitehouse.gov. Available at https://www.whitehouse.gov/the-press-office/2016/03/09/fact-sheet-president-obama-announces-connectall-initiative.

[13] The White House. Education. www.whitehouse.gov. Available at https://www.whitehouse.gov/issues/education/k-12/connected.

[14] The White House. Office of the Press Secretary. FACT SHEET: ConnectHome: Coming Together to Ensure Digital Opportunity for All Americans. www.whitehouse.gov. Available at https://www.whitehouse.gov/the-press-office/2015/07/15/fact-sheet-connecthome-coming-together-ensure-digital-opportunity-all; U.S. Department of Housing and Urban Development. ConnectHome. www.hud.gov. Available at http://connecthome.hud.gov/.

2009 (ARRA).[15] The Act authorized roughly $2.5 billion for (mainly last mile) network deployments in rural areas through the Broadband Initiatives Program (BIP) managed by RUS. It also authorized roughly $4.7 billion to support the Broadband Technology Opportunities Program (BTOP), managed by the National Telecommunications and Information Administration (NTIA). This included roughly $4 billion awarded to more than 200 broadband-related grants, plus $300 million allocated to a project in which states received funding to work under NTIA's direction to create a geographic database mapping the status of broadband availability down the Census Block level.[16]

Nearly nine of every ten BTOP dollars was invested in Comprehensive Community Infrastructure (CCI) projects, most of which were focused on extending fiber to community anchor institutions (CAIs) such as schools, libraries and government buildings.[17] A study of the BTOP program conducted by ASR Analytics estimated that these projects built a total of more than 42,000 miles of new fiber infrastructure, upgraded more than 24,000 miles of fiber,[18] and connected more than 21,000 CAIs.[19] Based on its analysis of a sample of 86 CAI locations impacted by CCI projects, ASR estimated that CCI projects—which were subject to BTOP's open access requirements[20]—led to dramatic 94-96 percent average reductions in the per-Mbps pricing that CAI's had previously been paying for their Internet connections.[21]

While these numbers are impressive, they say relatively little about the task of extending the broadband capacity now available to larger numbers of CAIs deeper into the communities they serve. While last mile fiber networks may be economically feasible for this purpose in some communities, the fact that CCI projects tended to be targeted at underserved areas suggests this is unlikely to be broadly the case.

This leads to the focus of this study: the potential to help bridge our nation's remaining divides in broadband access by developing innovative last mile strategies that leverage ongoing developments in wireless technology and regulation, combined with the increased availability and affordability of fiber backhaul linking our nation's public

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[15] American Recovery and Reinvestment Act of 2009. Public Law 111-5. Available at https://www.gpo.gov/fdsys/pkg/PLAW-111publ5/html/PLAW-111publ5.htm.

[16] Taglang, K. (2016, Mar. 1). "BTOP-BIP Brouhaha." Benton Foundation. Available at https://www.benton.org/node/146726.

[17] National Telecommunications and Information Administration (2013, Sep.) "Broadband Technology Opportunities Program (BTOP) Quarterly Program Status Report, Sept. 2013," at 1. Available at https://www.ntia.doc.gov/files/ntia/publications/ntia_btop_18th_quarterly_report.pdf; ASR Analytics (2014, Sep. 15). "Final Report: Social and Economic Impacts of the Broadband Technology Opportunities Program," Broadband Technology Opportunities Program Evaluation Study. Order Number D10PD18645. ("2014 ASR BTOP Evaluation Study") Table 7. Available at https://www.ntia.doc.gov/files/ntia/publications/asr_final_report.pdf.

[18] Ibid Table 28.

[19] Ibid Table 7.

[20] National Telecommunications and Information Administration. BroadbandUSA. "FACT SHEET: Broadband Technology Opportunities Program. Nondiscrimination and Interconnection Obligations." www.ntia.gov. Available at http://www2.ntia.doc.gov/files/Interconnection_Nondiscrimination_11_10_10_FINAL.pdf.

[21] 2014 ASR BTOP Evaluation Study, Table 13.

service-focused CAIs, thanks to government programs like BTOP and E-Rate, as well as other public and private investments.

To help policymakers and network planners better understand this potential, this report considers multiple spectrum bands, including those described briefly below, as applied to a range of geographic, topographic, institutional and application scenarios. The regulation, history and technical characteristics of these and other spectrum bands are discussed in more detail in our companion report focused on spectrum regulation.

Educational Broadband Spectrum (EBS)

As discussed in one case study and one example, EBS is well suited to solutions undertaken by educational institutions. It is also in a spectrum band able to leverage the large global volumes of LTE components, and to support mobile as well as fixed services. Its application is geographically limited, however, in that much of the nation's EBS spectrum has already been leased on a long-term basis to private providers, most notably Sprint, especially so in major markets. And, being located in the 2.5 GHz range, EBS spectrum faces challenges in terms of providing non-line of sight service.

Television White Space (TVWS)

As discussed in more detail in the accompanying regulatory analysis, the FCC has, over a period of years, taken steps to allow unlicensed use of TV channels previously used as guard bands to avoid interference between broadcast TV stations. As evidenced by multiple cases in this report, TVWS is currently evolving through relatively early stages of product and ecosystem development. And whereas it enjoys strong propagation characteristics relative to higher frequency bands, the impact of this technical advantage is currently constrained by FCC restrictions on power and antenna height.

As a tool for expanding access in underserved rural areas, TVWS has the benefit of being most plentiful in the nation's smaller and more rural markets, where broadband options tend to be fewer and slower. But, like its propagation strength, this advantage is somewhat hobbled by regulatory issues, since final decisions on TVWS availability will not be made by the FCC until it completes its ongoing incentive auction.

Additionally, because it operates as an unlicensed band, TVWS, while sparsely used today, is potentially vulnerable to the kind of interference-related challenges experienced in the existing Wi-Fi spectrum bands. That being said, it appears likely that interference issues, should they develop, will spur rapid and ongoing advancements in technical standards and innovative product design, as has been the case with Wi-Fi, which is today a foundational component of our nation's broadband infrastructure.

Wi-Fi Mesh Networks

While multiple projects included in this report use Wi-Fi hotspots as the final connection link for end users, one case considers how Wi-Fi mesh networks managed and maintained by local community members can provide a means to achieve low-cost neighborhood-level connectivity that can grow organically and dynamically based on local conditions and needs.

The focus of this case is the Wi-Fi mesh network developed in Red Hook, NY, a part of Brooklyn that was hard hit by Hurricane Sandy in 2012. Developed by a local non-profit, Red Hook Initiative (RHI),[22] in partnership with New America Foundation's Open Technology Institute (OTI),[23] the Red Hook Wi-Fi network—and the OTI-trained team of homegrown Digital Stewards that maintain it—proved to be a valuable resource during and after the storm. More recently, this experience helped OTI and Red Hook WiFi win grant funding from the New York City Economic Development Corporation (NYCEDC) to adapt the model they co-developed to neighborhoods and small businesses in all five NYC boroughs. The funding came through the RISE: NYC program, which NYCEDC describes as "a Superstorm Sandy business recovery and resiliency program that helps New York City small businesses adapt to and mitigate the impacts of climate change through the use of innovative technologies."[24]

Millimeter Waves

One case study and one example in this report involve the use of Millimeter Wave (mmW) technology. As discussed in our spectrum regulation report, the FCC has authorized use of mmW spectrum on a "lightly licensed" basis in the E band, which is found in the 70, 80, and 90 GHz portions of the mmW spectrum, along with unlicensed use in the V band, located in the 50 and primarily 60 GHz range.

Among the key advantages of mmW spectrum is that it can support gigabit-speed wireless links at relatively low cost and with small antenna sizes. It also tends to be relatively robust when it comes to interference and security, given its very narrow beamwidths. The key weakness of mmW is the relatively severe signal loss it experiences when subjected to heavy rain, and for some mmW frequencies, from oxygen absorption. Due to these limitations, mmW is typically used for short links.

In one of the report's case studies we examine how Cruzio Internet, sometimes working with the City of Santa Cruz, California, is using E band mmW links to deliver gigabit speeds to office buildings and multiple dwelling units (MDUs) in an urban setting. We also discuss how the city of Fort Myers, Florida, facing an urgent need for improved security following a shooting at a public event, was able to quickly deploy a V-band network connecting 49 high-resolution surveillance cameras in its downtown area.

[22] Red Hook Initiative. Home. http://rhicenter.org/.
[23] New America. Open Technology Institute. About Us. www.newamerica.org. Available at https://www.newamerica.org/oti/about-us/.
[24] Rise: NYC. http://rise-nyc.com/.

OUR RESEARCH APPROACH

In selecting the in-depth and supplementary cases to be examined in this study, the research team developed a selection framework that was anchored in several key factors. These included: (i) the nature of the connectivity need being addressed (e.g., bridging the homework gap for students, deploying public-access hotspots, connecting college campuses, CAIs and/or multiple dwelling units); (ii) the environment in which a connectivity solution is deployed (e.g., where it falls on the urban/rural scale, and wireless communication-related topographical features); (iii) the specific spectrum band(s) employed (which range from below 1 GHz to above 80 GHz) and; (iv) the institutional factors involved (ownership, partnerships/alliances, organizational missions and constraints, mix of stakeholders, etc.).

Based on an initial round of research and discussions among the project team and advisory board, as well as outside experts, we developed the framework outlined below, which considers all of the above factors, but focuses most intensively on the nature of the particular connectivity need being addressed.

1. Using Wireless to Better Serve Students
    a. Beyond Campus (i.e., bridging the homework gap)
    b. Between and around campuses (supporting on campus hotspots and deploying cost-effective high-capacity links between remote campuses)
2. Community Anchor Institutions and Municipalities Using Wireless to Extend and Enhance Their Services
    a. Extending library-provided Internet access via community hotspots
    b. Providing backup links for emergency communication
    c. Video surveillance and other “smart city” applications
    d. Low-cost support for non-profit community services
    e. Using telemedicine applications to improve rural healthcare services
3. Privately-owned ISPs Using Wireless to Improve Internet Access
    a. Rural areas with challenging terrain and weather
    b. Urban areas containing relatively dense concentrations of multiple dwelling units and office buildings.

Within this framework we selected five cases for in depth study, supplementing these with a more limited review of seven additional examples that help paint a fuller picture of potential applications, environments, institutional participants and other stakeholders, as well as key challenges and strategies to overcome them. Among the key factors impacting our choice of in-depth case studies was the extent and reliability of available information about them, and the extent to which the research team and advisory board viewed them as likely to shed helpful light on key issues and challenges, and opportunities for broader application and social impact beyond the particular project being examined. We included at least one case study for each of the three main categories listed above, with the first and last of these featuring two case studies each.

A somewhat differently structured view of our case selection framework is provided in the table below, which summarizes key characteristics of each of the twelve cases included in the report.

Cases Included in This Report[25]

Case	Connectivity Need	Type	Spectrum	Institution(s)	Environment
NMU/Merit	Homework gap	CS	EBS	College; REN	Rural
Albemarle	Homework gap	E	EBS	K-12	Rural
Mid-Atlantic Broadband	Homework gap	E	TVWS	K-12; Fiber back-haul wholesaler	Rural
Brookdale	1 Gbps links to remote campuses	CS	11 GHz Fixed Microwave	College	Rural
WVU	Backhaul for campus transit hotspots	E	TVWS	College	On-Campus
Manhattan, KS	Hotspots; emergency communication backup	CS	TVWS	Library; Gigabit Libraries Network	Small town
Wilmington, NC	Hotspots; surveillance & sensor networks	E	TVWS	Municipality	Small city
Fort Myers	Video surveillance	E	mmW	Municipality	Small cities
Red Hook WiFi	Community services; emergency communication	E	Mesh Wi-Fi	Local NGO	Dense urban
Botswana	Telemedicine	E	TVWS	Multiple	Rural Africa
Axiom	Remote rural access	CS	Multiple, incl. TVWS	Privately owned local ISP	Rural Maine
Cruzio	Expand access, speed, choice in urban market	CS	Multiple, incl. mmW	Privately owned local ISP	Mid-size city in hi-tech region

[25] The Type category is designated as either Case Study (CS) or Example (E).

REVIEW AND ANALYSIS OF CASES

The first five of the dozen cases examined in this report focus on the use of wireless communications to better connect and better serve students. The first three of these, which include one case study and two additional examples, focus on improving connectivity for students lacking affordable (or, in some cases, any) broadband access at home. This is followed by a case study focused on linking remote campuses with gigabit-speed connections, and an example in which a university uses wireless backhaul to support Wi-Fi hotspots at campus transit stops.

We then examine five cases involving the use of wireless by Community Anchor Institutions (CAIs) and municipalities to extend and enhance their services. These include one case study and four additional examples, covering a range of applications, including support for public hotspots, video surveillance, remote sensor-based monitoring, community service-focused apps, emergency communications and telemedicine.

Our final two case studies focus on situations in which privately owned ISPs use wireless to improve Internet access in the communities they serve. The first focuses on a rural service area that includes very remote locations and challenging terrain and weather. The second focuses on an urban area that includes relatively dense concentrations of multiple dwelling units and office buildings.

Bridging the Homework Gap

The case studies and examples in this section of the report focus on efforts to bring broadband connectivity to students when they are away from school, particularly when they are at home. As a result of what has become known as the "homework gap,"[26] a portion of our nation's students—often those in rural and low-income areas—are at growing disadvantage in their efforts to get a high-quality education. And, as more and more schoolwork and school-related communications become Internet dependent, the risks associated with this homework gap are increasing.

This section's case study and one of its examples focus on the use of EBS spectrum to connect students after they leave school. The former focuses on a joint project between Merit Network, a Research and Education Network (REN) providing fiber connectivity services to Michigan's educational and other CAI communities, and Northern Michigan University (NMU), one of Merit's university member-owners. As discussed in our case study of this project, it is ambitious and noteworthy in several respects, including:

1. Its use of the full array of 112.5 MHz of EBS spectrum, which was authorized by an FCC waiver granted to NMU after the university had deployed a smaller-scale project (in terms of both geography and spectrum) that targeted its own students and staff;
2. The expansive geographic scope of the project, which encompasses most of Michigan's largely rural and underserved Upper Peninsula
3. The institutional/market scope of the project. In addition to the central roles played by NMU and Merit, the network will also serve students affiliated with other higher education and K-12 educational institutions, and potentially also other CAIs, including local governments and libraries.

Our second case using EBS spectrum involves the Albemarle County Public School (ACPS) district in Virginia. Like the NMU/Merit project, the ACPS initiative is one of the nation's first projects deploying LTE technology using EBS spectrum. But unlike that Northern Michigan project, ACPS is currently able to use only the 22.5 MHz of spectrum for which it holds a license, with other EBS spectrum in the local area currently licensed to other entities. The ACPS project involves a close working relationship with local public safety agencies, including cooperation on antenna siting which, as discussed at several points in this report, is an important factor in determining a wireless project's economic feasibility and technical performance.

Unlike the first two, the final case examined in this section uses TVWS rather than EBS spectrum. It is significant for several reasons:

1. it is one of the nation's first projects aiming to bridge the homework gap by transmitting TVWS signals directly to students' homes;
2. it will be using a newer generation of TVWS equipment than most TVWS projects deployed in the U.S. and reviewed in this report;

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[26] Horrigan (2015). Supra n. 3.

3. it plans to scale well beyond existing U.S. TVWS projects, in terms of the number of base stations and homes connected, and the speed of the backhaul connections it delivers to its TVWS base stations; it will also employ higher transmit powers and antenna heights than most other U.S. TVWS projects launched to date;
4. the project's participants—which include Microsoft, fiber backhaul wholesaler Mid-Atlantic Broadband Communities Corporation (MBC), and the Charlotte and Halifax County Public Schools—have asked the FCC to clarify whether and how the two district's E-Rate funding will be impacted by the use of some E-Rate-supported fiber bandwidth to supply backhaul capacity for wireless connections to students' homes.[27]

[27] Federal Communications Commission (2016). "Wireline Competition Bureau Seeks Comment on Petitions Regarding Off-Campus Use of Existing E-Rate Supported Connectivity." Public Notice in CC Docket No. 02-6; WC Docket Nos. 10-90, 13-184. Released Sep. 19, 2016. ("2016 E-Rate Public Notice"). Available at https://apps.fcc.gov/edocs_public/attachmatch/DA-16-1051A1.pdf; Federal Communications Commission (2016). Modernizing the E-Rate Program for Schools and Libraries. "Joint Petition for Clarification or, in the Alternative, Waiver of Microsoft Corporation, Mid-Atlantic Broadband Communities Corporation, Charlotte County Public Schools, Halifax County Public Schools, GCR Company, and Kinex Telecom," in WC Docket No. 13-184. June 7, 2016. ("2016 E-Rate Petition.") Available at https://ecfsapi.fcc.gov/file/60002098542.pdf.

Case Study: Northern Michigan University and Merit Network using EBS to bridge the homework gap in Michigan's Upper Peninsula[28]

Merit Network and Northern Michigan University are working together on a project designed to use EBS spectrum to alleviate the "homework gap" in Michigan's extremely rural Upper Peninsula (UP).[29] The partnership intends to accomplish this by enabling individuals enrolled in educational and training programs to have broadband access at home and throughout their communities.

NMU is located in Marquette, Michigan and serves approximately 9,000 students with over 1,100 faculty and staff.[30] All NMU full-time students are issued a university-supplied notebook, with more than 9,600 devices currently capable of utilizing the NMU network. However, some students enrolled at MNU (and other educational institutions) do not have broadband access in their homes or local communities, limiting the educational value they can extract from these devices.

NMU has constructed and is operating a wireless network that relies on EBS spectrum to cover approximately 230 square miles in the UP.[31] Having received an FCC waiver in early 2016, and in cooperation with Merit Network, NMU is undertaking a new and major expansion of its EBS network that will greatly expand its footprint and make its services available to students, faculty and staff associated with other education-focused institutions in the state. A brief summary of the network's history is provided below.

On December 4, 2007, NMU filed an application seeking FCC authorization to use four EBS channels.[32] On August 6, 2008, the FCC's Wireless Telecommunications Bureau granted NMU a waiver of its longstanding filing freeze on new EBS applications, subject to several conditions, including that NMU not lease any of the EBS spectrum to other entities (as had often been done with licensed EBS spectrum).[33]

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[28] This case study is largely informed by the authors' interviews with representatives from Merit Network and Northern Michigan University (in person interview on Aug. 3, 2016).

[29] As discussed in substantial detail in accompanying regulatory analysis, EBS is an educational service that has generally been used primarily for the transmission of instructional material to accredited educational institutions. See Federal Communications Commission. BRS & EBS Radio Services. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=service_home&id=ebs_brs.

[30] Northern Michigan University, About Northern Michigan University. www.nmu.edu. Available at http://www.nmu.edu/about.

[31] Federal Communications Commission (2016). "Applications of the Board of Trustees of Northern Michigan University for new Educational Broadband Service Stations." Memorandum Opinion and Order in File Nos. 0007030772-0007030777. Adopted Apr. 4, 2016. Released Apr. 5, 2016. ("2016 NMU EBS MO&O") Available at https://apps.fcc.gov/edocs_public/attachmatch/DA-16-358A1.pdf.

[32] Northern Michigan University (FRN: 0003250992). FCC Form 601: Applications for Educational Broadband Service ("EBS") Licenses. Exhibit A: Request for a Wavier. Filed Dec. 04, 2007. Granted Aug. 08, 2008. Available at http://wireless2.fcc.gov/UlsApp/ApplicationSearch/applMain.jsp?applID=4239375.

[33] Federal Communications Commission (2008). "Applications of the Board of Trustees of Northern Michigan University for new Educational Broadband Service Station." Memorandum Opinion and Order in File No. 0003250992. Adopted Aug. 6, 2008. Released Aug. 6, 2008.

In 2008 NMU began using EBS spectrum to deploy a WiMAX network (see NMU WQST793-802 geographic service area in Figure 1). Subsequently, NMU requested and received FCC approval to expand the number of EBS channels it used, and also began a transition from WiMAX to LTE, a process now largely complete. In April 2016, NMU was granted a waiver by the FCC to use 112.5 megahertz of EBS spectrum throughout much of the UP, as depicted in the circular geographic service area (GSAs) in Figure 1 (each circle on the map represent a 35 mile radius).[34]

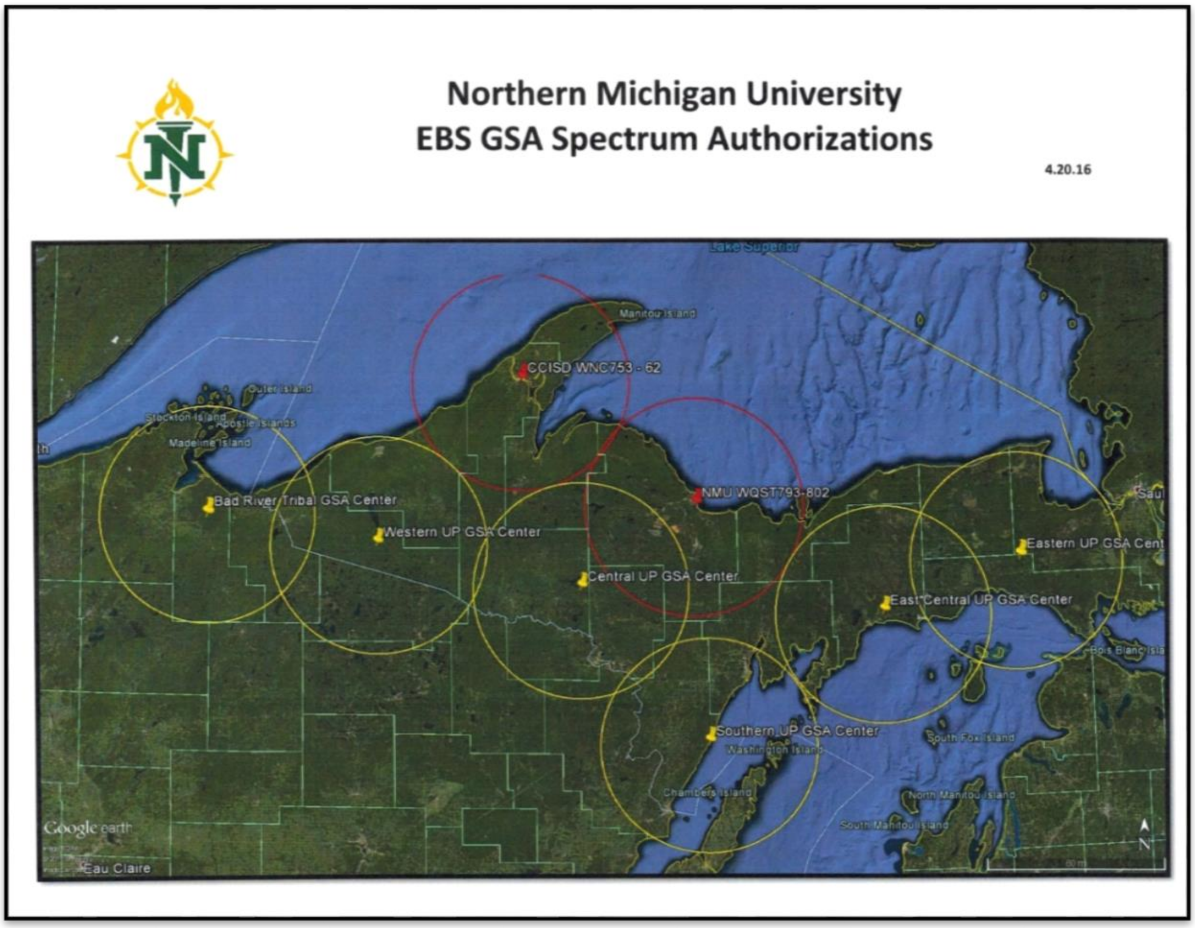

Figure 1: NMU EBS Licenses[35]

The LTE equipment used in the NMU network is provided by Huawei. Huawei, which has constructed (EV)DO based systems[36] throughout the United Kingdom and

("2008 NMU EBS MO&O") Available at http://wireless2.fcc.gov/UlsApp/ApplicationSearch/applAdmin.jsp?applID=4239375#.

[34] 2016 NMU EBS MO&O.

[35] Figure courtesy of Merit Network and Northern Michigan University.

[36] EVDO, or Evolution Data Optimized, is a third generation (3G) mobile broadband technology which has since been displaced by 4G LTE. See for instance Federal Communications Commission. Long Term Evolution (LTE) Public Safety Information Sheet. www.fcc.gov. Available at https://transition.fcc.gov/pshs/docs/LTE_Info_Sheet_09082010.pdf.

Continental Europe, was chosen in part because other major vendors were not interested in supplying LTE deployments on the relatively small scale of the NMU project.

The network core is a full LTE core that can handle up to 200,000 users. As of July 2016, the core had received three software updates, but at some point will need to be replaced, particularly if vendor hardware/software support ceases. NMU CIO Dave Maki estimates that the network core will last for 8-10 years.

Each cell within the current network has 100 Mbps (theoretical maximal) throughput capacity per 15 megahertz channel. Accounting for overhead, this translates into 85-90 Mbps download capacity and 30-35 Mbps upload, shared by all simultaneous users of a given cell. NMU hopes to add another 5 megahertz per channel in order to increase the maximal throughput to 150 Mbps.[37] The network is generally configured for 90 percent download and 10 percent upload.

Once the latest generation of devices—"Category 6"— has been more broadly adopted, cell aggregation using two 15 megahertz or 20 megahertz blocks of spectrum can be used to make a single wider channel to double the maximum throughput. Combining aggregation with two 20 megahertz channels could support theoretical maximum throughput of 300 Mbps per cell.

Currently, however, a category 6 device might cost $400 relative to a comparable $100 category 5 device. This makes an upgrade to category 6 devices economically challenging for consumers until increased production volumes drives down costs for such devices.

Customer Devices

Each individual network user is assigned a SIM card with a unique fixed IP address. The SIM cards may be included with a device or can be separately shipped to the user. The current plan is to provide devices with the SIM card installed, which is what NMU has been doing when it provides students with laptops.

SIM cards are compatible with various standard devices (e.g., iPad, Microsoft Surface tablet, etc.), as well as indoor desktop and outdoor antennas. To access the EBS/LTE network, the device must support LTE band 7 or 41 (LTE in the EBS and Broadband Radio Service bands), which is increasingly common in current-generation devices.[38] In addition, users who own dual-SIM devices will be able to access NMU's EBS network and also access an alternative mobile wireless service using a single device.

NMU CIO Dave Maki expects the price point for indoor end user devices to remain in the $70-$110 range, with performance improving over time (e.g., a transition from

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[37] The accompanying regulatory analysis describes the EBS band plan. In particular, EBS consists of five 22.5 megahertz blocks. However, out of the 112.5 megahertz of EBS, the FCC only considers 89 megahertz suitable and available for telephony/broadband services.

[38] See for instance, Sprint (2016, Feb. 18). Sprint Newsroom. Sprint Continues to Close the Gap in Overall Network Performance. www.sprint.com. Available at http://newsroom.sprint.com/blogs/sprint-perspectives/sprint-continues-to-close-the-gap-in-overall-network-performance.htm.

Category 4 and 5 to Category 6 devices), as is common in the broader wireless device market.

Expanding the Network

In terms of network expansion, current plans are to initially launch 16 antenna sites and to have 16 to 20 sites operational by Spring of 2017. Merit is currently operating a pilot deployment targeting existing NMU areas plus Escanaba and Ironwood, MI. These are considered good areas for expansion due to the presence of both K-12 and community college facilities.

NMU is currently transmitting mainly at 20 watts of power, with new Time Division Duplex (TDD) sites transmitting at 30 watts. At these power levels, mobile devices such as laptops, tablets and cellphones with line-of-sight access generally can receive good connections up to 3 miles from antenna sites. As distances expand beyond 3 miles to a maximum of 9 miles, indoor table-top and (as distance increases) outdoor antennas (e.g., mounted on rooftops) are required.

Within the original network coverage area, the full LTE deployment will make use of fiber backhaul. However, where necessary, backhaul will be provided via licensed point-to-point spectrum in the 11 GHz and other bands. As of August 2016, four of 15 antenna sites were employing wireless backhaul. NMU has explored unlicensed spectrum as well, but both it and Merit prefer to use licensed spectrum when possible, in large part because its use is protected from interference.[39]

In the UP, tower leasing is uncommon, though leasing or construction of new towers may be required in the future as the network matures. More common today is for NMU or Merit to allow a municipality to use some network capacity at no charge if existing municipal infrastructure can be utilized for equipment deployment. For example, municipal water towers and other towers or sufficiently tall buildings close to Merit's existing infrastructure have been identified as ideal to meet the current construction requirement while also mitigating costs. All antenna sites currently have 2-hour battery backup, with most also having backup generators.

Developing and Refining the Business Model

Merit currently envisions two classes of service: K-12 and non-K-12, with the former including content filtering. As of early August 2016, Merit was attempting to identify organizations within the anticipated coverage area that are interested in the LTE service.

The current plan is to have each participating organization procure a number of devices (e.g., 200) and to pay a monthly fee for each individual user, with no data caps. The monthly price point would aim to balance Merit's educational mission with the need to employ a sustainable business plan that, among other things, takes into account the geographic limitations of the NMU/Merit private network service, which does not have roaming contracts with other service providers. Merit anticipates that the monthly fee may need to be adjusted in the future, depending on how the project evolves.

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[39] A detailed overview of common fixed microwave bands and associated developments is available in the accompanying regulatory analysis.

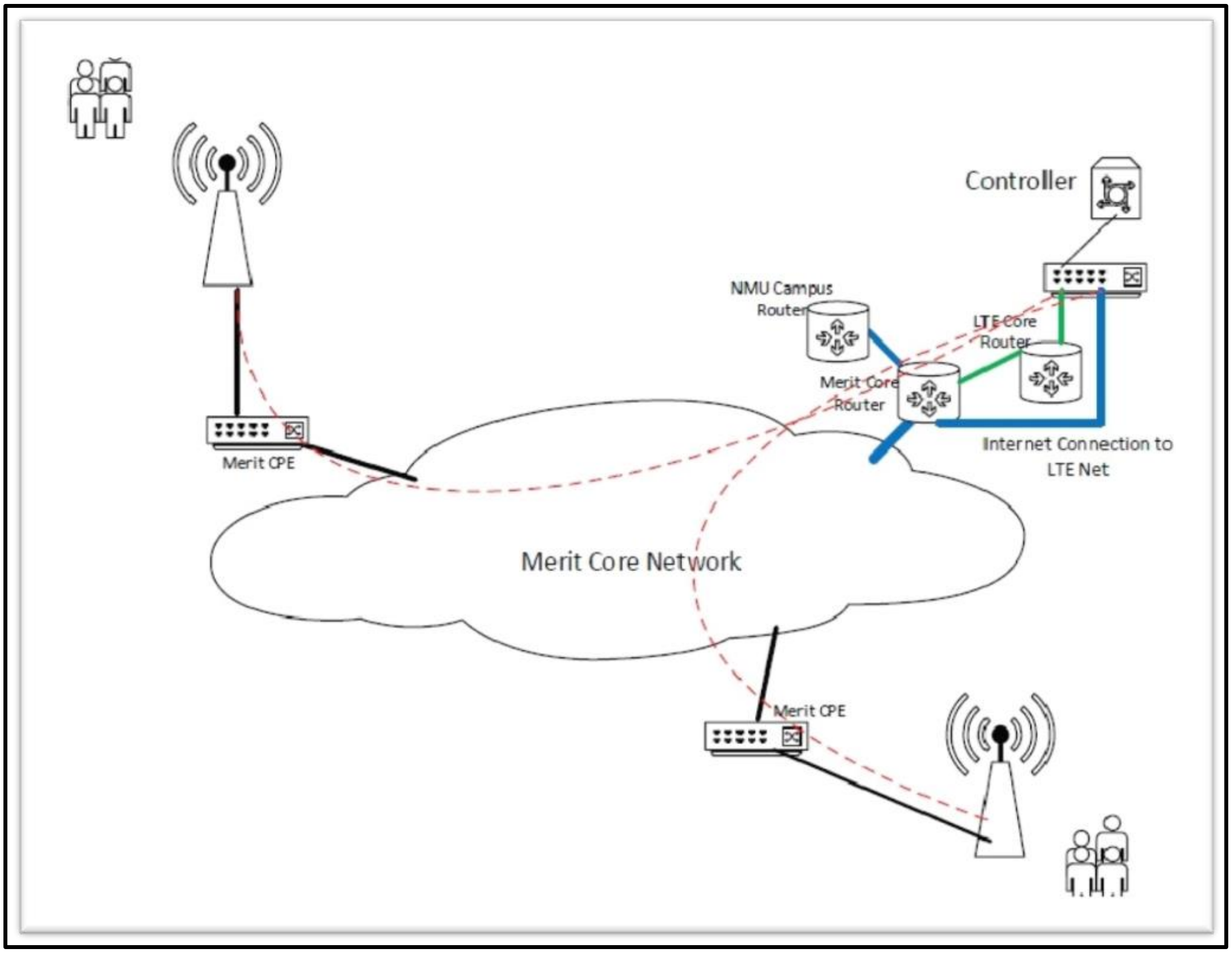

Figure 2: LTE Network Architecture[40]

As noted above, NMU sometimes exchanges some amount of network usage with a municipality in exchange for access to water towers and other municipal facilities for antenna siting. NMU has discussed this arrangement with the FCC in relation to its EBS waiver, and did not meet resistance to it from Commission staff, nor to potential use by public libraries or other governmental entities, such as Michigan Works, a system of regional agencies focused on supporting employment opportunities in the state.

In situations where Merit member/customer organizations are consortiums (e.g., a library consortium), Merit offers a billing model in which the consortium aggregates all traffic generated by its members into a single bill paid by the consortium, which then bills its member organizations. If members' peak usage occurs at different times (e.g., libraries open on different times/days), this aggregated billing arrangement allows them to get more benefit from the network by balancing total peak usage levels among member organizations.

Although Merit anticipates offering a service plan with unlimited data usage (in contrast to most "data capped" wireless data plans available from cellular providers), there will be limits on throughput. Tests undertaken by NMU indicated that, when maximum data

[40] Figure courtesy of Merit Network and Northern Michigan University.

rates were reduced from 25 Mbps download and 5 Mbps upload to 15 Mbps download and 5 Mbps upload, individuals did not call in to complain, suggesting that they may have not notice this change. This was a helpful development because a guarantee of 25 Mbps down and 5 Mbps up would likely put stress on the network, particularly from heavy users located at the network coverage periphery. As of August 2016, the plan was to provide a maximum throughput of 10 Mbps download and 2 Mbps upload.

Initially, Merit will use current usage behavior at NMU—in particular, the number of registered versus typical simultaneous users—as a predictor of total community usage. The current expectation is that for every three users, one will be on during the daytime. Based on these projections and the number of expected users, Merit has assumed that, on average, each user will consume a continuous 1 Mbps. Based on this average and the network's projected capital expenditures (CapEx), operating expenditures (OpEx) and rate structure, Merit will set an initial monthly price point designed to achieve cost recovery within a reasonable time frame while remaining competitive.

Merit's planning indicates that the initial breakeven expectation based on current costs and planned pricing will require approximately 1,500 users across all sites. Merit expects a 4-5 year cost recovery on the project, though this may need to be reevaluated based on depreciation, changes to technology and how the project evolves.

Merit staff noted the importance of ongoing measurement of usage and other factors, and revisiting assumptions and plans based on actual network usage, performance, costs, etc. For example, it is not clear that the "three registered users to one active user" ratio will apply to other Upper Peninsula communities as the user base expands beyond its current scope.

The current plan is for technical support to be offered by the host organization (e.g., school) to its end users, with Merit providing support to the host organization. Additionally, the LTE network will be offered as a best effort service. In the event of a service outage, Merit/NMU view an acceptable response time as 12 hours for a local tower outage and 4 hours for the core network. End users will contact their host organization in the event of an outage unless they purchased the service directly from Merit/NMU.

In terms of security, all wireless data on the network will be encrypted, with responsibility for compliance with HIPAA and similar requirements falling to the organization sending the data. The network is also capable of copyright violation (e.g., via Bit Torrent) detection.

Capital and Operating Costs

The following comprise the project's major capital expenditures:

- Costs to connect tower sites and base stations to the core network: These vary from site to site according to geography, site preparation requirements and other factors.
- Site preparation tasks also vary by site, and could include procuring power, protected power, and space for electronics. Locations close to Merit's existing

infrastructure are preferred. Fiber located near a tower and/or a telecom hub suggests a source of protected power and a place for equipment.

- Backhaul is one of the most important considerations that impacts CapEx.
- “Lighting” towers includes connecting routing equipment and base stations.
- Licensing: e.g., SIM cards are generally licensed 1,000 users at a time. Likewise, licenses for devices must be procured.
- Network core investment (NMU has already done substantial work on this end).

Merit will be largely responsible for CapEx related to getting fiber or other backhaul to the sites, with NMU responsible for CapEx to light up towers and base stations. Current plans call for NMU to continue owning the LTE equipment and Merit continuing to own backhaul, reflecting their existing asset base, expertise, and operational responsibilities.

This project involves relatively insubstantial spectrum acquisition/licensing costs. Costs include those related to filing an EBS waiver and other FCC related paperwork as well as any costs of procuring fixed point-to-point licenses where necessary for microwave backhaul.

Major operating expenditures for the project include ongoing maintenance for cell sites, equipment space and power, network connections, base stations, user licensing, fiber maintenance, backhaul and core network

Network and Service Management Software

NMU has designed a software system that manages its internal Educational Access Network, including network and equipment status, outage information, etc. A separately branded version of the software will also be used for the expanded service offering that NMU is undertaking in partnership with Merit. Key elements of that system which, as explained by Maki, allows users to be assigned maximum down and up Mbps thresholds, and tracks traffic, usage, and congestion on a continual basis, are summarized below.

The system supports multiple user levels. For example, a “super user” can manage other Access Point Names (APNs). More specifically, for instance, the administrator for the Bad River Tribal GSA (see Figure 1) will monitor all Bad River users, whereas Dave Maki or the overall network manager can observe all users.

Individuals and institutions can register as network users via an online interface linked to the management software by entering information such as their name, number, address, and e-mail.[41] NMU uses Google geo-mapping to designate coordinates for a user based on their inputted address. The software then makes recommendations with regard to what hardware a user might wish to purchase depending on user type and location relative to the nearest cell site (e.g., depending on distance, this could include a mobile device or an indoor/desktop or outdoor antenna).

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[41] Additional information regarding connecting to the NMU network is available at: Northern Michigan University. LTE Network at NMU. https://www.nmu.edu/lte.

The user obtains an initial verification indicating where they are located relative to the nearest tower, and can pay online for service and devices. The user has an option to pick up or get delivery of the recommended equipment. NMU does not recommend any particular contractors for outdoor installation, leaving this decision to the end user. Its website does, however, provide helpful information related to equipment installation.

The system supports multiple methods for registering users, including individual registration or institutions providing bulk lists of qualifying students. Similarly, individuals can purchase devices or the school can purchase them for all or a select subgroup of their students. For example, a school could choose to purchase devices for low income students but allow higher income students to purchase directly from NMU (this way, the network is available to all, and affordable for those in need of financial assistance). The user is billed through a credit card or through an institutional account.

A question being considered by NMU and Merit is how the network can be configured to permit individuals affiliated with other Merit member (e.g., students enrolled in other state colleges in MI) to access the LTE network when they visit the UP. It appears that this is technically feasible. Also technically feasible, though not currently planned, is the possibility of expanding this access to include students attending out-of-state schools.

Using the online registration system, individuals can purchase network access as part of a bundle when they enroll for NMU courses. This raises the possibility that individuals in underserved areas may enroll in a low credit (inexpensive) course for the specific purpose of obtaining network access if access is unavailable from other service providers. Students with existing broadband service can also register for classes without signing up for the NMU LTE service.

Individuals using the network are bound by an acceptable use policy, and the system includes software to protect copyrighted material.

Example: Albemarle County Public Schools using EBS to bridge the homework gap for K-12 students[42]

For the past several years, Albemarle County Public Schools (ACPS) has been developing an EBS-based wireless network to help bridge the homework gaps that exist among the roughly 13,700 (preschool to grade 12) students it serves in Albemarle County, Virginia, the state's sixth largest county by area.

A diverse region of 726 square miles in the heart of Central Virginia, Albemarle County is a blend of primarily rural but also suburban and urban settings.[43] The latter includes Charlottesville, VA, an urbanized college town with adequate broadband connectivity. However, approximately 50 percent of ACPS students live in 680 square miles of rural and suburban areas, much of which lacks adequate broadband coverage.

The project's research team interviewed Vincent Scheivert, ACPS's Chief Information Officer. Albemarle has five engineers (four network engineers and a software engineer), though they are not fully devoted to wireless deployment. Scheivert also works with various population groups and school principals to coordinate services.[44]

As Scheivert explains, the policy of ACPS management is that "all means all" when it comes to ensuring adequate broadband coverage. Put another way, Scheivert noted that schools are not comfortable handing out textbooks to students situated in only certain places, the same should be the case for information and communication technologies (ICTs) that are increasingly necessary for students to receive a modern education. This "all means all" attitude is reflected in ACPS's policy of providing all students with wireless-capable laptops, starting at the 4th grade level (though only students in 6th grade and above are allowed to take the laptops home).

Scheivert also noted that the ACPS school board supports the wireless project and views it as part of its strategic mission. Making this somewhat simpler and easier, is the fact that the board does not have taxing authority, so is able to concentrate on what is best for students without getting directly involved in politically charged taxation issues.

The project deployed LTE using 22.5 MHz of EBS spectrum licensed to the school district. The spectrum had earlier been leased to a private company, but was reclaimed by ACPS around 2010 after the company stopped making lease payments to ACPS during the economic downturn.

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[42] The discussion of this example is largely informed by the authors' interviews with Vincent Scheivert, Chief Information Officer, working in Albemarle's County Public Schools Department of Accountability Research and Technology (phone interview on Aug. 15, 2016).

[43] Albemarle County Public Schools. About Us. www.k12albemarle.org. Available at https://www2.k12albemarle.org/acps/division/Pages/default.aspx.

[44] Albemarle County Public Schools. The Department of Accountability Research and Technology. Organization Chart. www.k12albemarle.org. Available at https://www2.k12albemarle.org/dept/dart/Documents/DART-Org-Chart.pdf; Albemarle County Public Schools. "ConnectEd Albemarle" Demonstration Project Background. www.k12albemarle.org. Available at https://ecfsapi.fcc.gov/file/7521096572.pdf.

As of mid-August 2016, the school district was operating a macro cell that served a 15-17 square mile area, plus approximately 10 microcells served by antennas mounted on school roofs, each covering a 1.5-2 sq. mi. radius. Each school is connected to fiber backhaul. ACPS is also using EBS spectrum to provide a backhaul link to a Wi-Fi network that serves a low income community comprised mainly of trailers that is home to approximately 300 students.

Scheivert said that current network coverage is fairly good near the macro cell, including some in-building penetration. However, further away from the macro cell Wi-Fi is necessary for in-building penetration. ACPS's goal is to have full coverage throughout the county by the 2019 school year. Its network deployment plan calls for some antennas to be mounted on existing public safety towers and other existing infrastructure that is already fiber connected. In the future, ACPS hopes to add two or three more macro cells and additional spectrum as overlapping EBS leases expire.

Noting that the ACPS deployment was too small to attract large equipment vendors like Ericsson and Motorola, Scheivert said that the project's equipment is currently being provided by Airspan.[45]

As of our August 15 interview with Scheivert, ACPS was serving subscribers that number in the hundreds and had ordered well over a thousand end user devices. Scheivert noted that equipment sometimes takes a long time to obtain because of the low quantities ordered. Once it is available, ACPS contacts students' homes via an automated phone call to inform them of equipment availability. This is followed by a meeting at an elementary school to distribute devices. Based on the current plan, the only cost to students' families is the cost of the in-home equipment needed to receive the signal. Though the network currently only supports devices provided to students, these have the potential to be used by other family members, though such usage would be subject to the school district's content filters.

In the future, ACPS envisions the network supporting a range of devices, including portable personal Wi-Fi hot spots, as well as equipment that can be mounted on a police car or school bus. The purpose of the latter is to allow students to get online while traveling to and from school, which can total nearly an hour for some students.

Scheivert cites local public safety agencies as key allies in the project. Though often reluctant to share resources, including spectrum, these agencies already have a working relationship with local schools, which serve as Wi-Fi hotspots for police and fire departments. This existing relationship smoothed the path to working out cooperative arrangements for tower colocation and backhaul.

As part of this ongoing relationship with public safety agencies, Scheivert noted that local police departments were involved with proof-of-concept deployments designed to test the network's support for mobility and in-building penetration. He explains that, for the past two years, the network has supported security-related functions for a highly-attended local event (a steeplechase race) held twice a year. As he put it, "LTE worked great for this purpose." Libraries, on the other hand, are not currently involved in the

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[45] Airspan. http://www.airspan.com/.

EBS project. In particular, local public libraries in the county are managed under a different organizational unit and receive technical services elsewhere.

The project's largest obstacle, noted Scheivert, is people not believing that a local school district could provide a service that large companies like AT&T and Verizon have opted not to offer. He also believes the approach taken by ACPS is replicable by other school districts, especially those with a preponderance of fiber-connected schools. This is true, even for more sparsely populated areas, where a regional approach could help make such a project viable. At the same time, he noted that a key variable is the extent to which EBS spectrum is available for such uses, rather than being leased on a long-term basis to private companies. He adds that FCC funding for educational entrepreneurs would improve the prospects for wider adoption of EBS-based solutions to the homework gap.

Example: Microsoft, Mid-Atlantic Broadband and Charlotte and Halifax County Public Schools using TVWS to bridge the homework gap for K-12 students[46]

Though still in early stages of development, a project underway in Charlotte and Halifax counties, Virginia, aims to develop a model for using TVWS to bridge the homework gap in underserved rural areas around the country. The project is being spearheaded by Microsoft, which has supported multiple TVWS projects around the world[47] (including others discussed in this report), and Mid-Atlantic Broadband Communities Corporation (MBC), a 501(c)(4) non-profit corporation focused on providing wholesale open access capacity on its more than 1,800 route miles of fiber in support of economic development in the Southern Virginia region.[48]

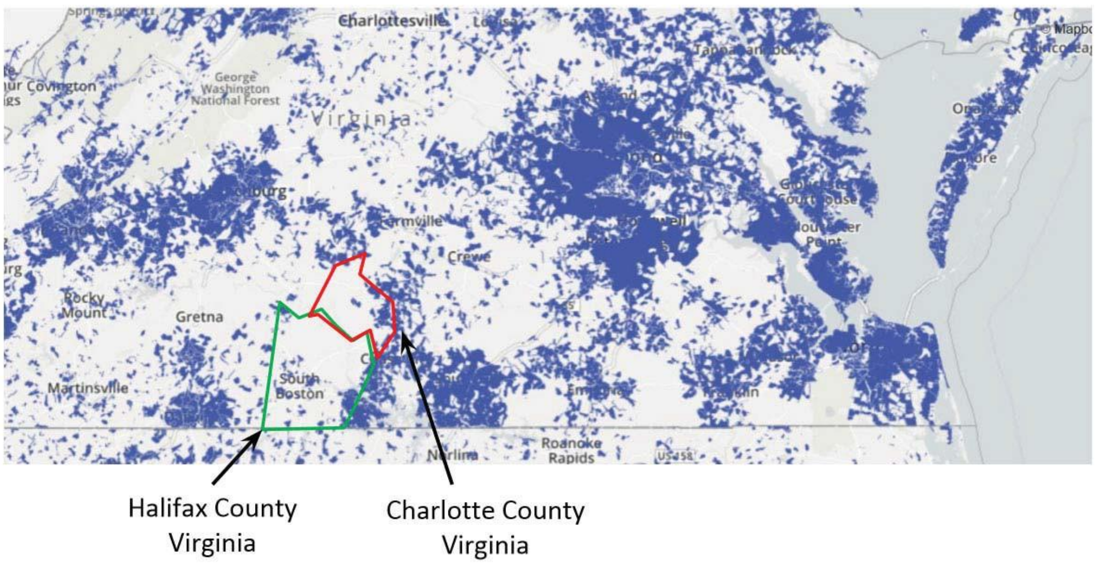

Figure 3: Charlotte County and Halifax County Broadband Availability, 1.5 Mbps to 10 Mbps[49]

Because the project's two target counties are very rural, with limited broadband availability (see sparse coverage depicted in Figure 3) and low average incomes,[50] according to the two school districts' superintendents, roughly half of the participating school's students lack at-home broadband connectivity.[51]

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[46] Our discussion of this project is based mainly on an October 18, 2016 Skype interview with Tad Deriso, President and CEO of MBC, along with a filing submitted to the FCC by the project's principals (2016 E-Rate Petition. Supra n. 27).

[47] Microsoft (2012, Nov. 30). Dynamic Spectrum and TV White Spaces. www.microsoft.com. Available at https://www.microsoft.com/en-us/research/project/dynamic-spectrum-and-tv-white-spaces/.

[48] MBC. Mid-Atlantic Broadband Communities Corporation. www.mbc-va.com. Available at http://www.mbc-va.com/about-mbc/.

[49] 2016 E-Rate Petition, at 9, Figure 1, n. 20.

[50] Ibid nn.18-23.

[51] Ibid at 8 and attached declarations.

The goal of the project is to extend to students' homes the education-focused Internet connectivity they enjoy at school with no additional cost to schools, students, or the Universal Service Fund's E-Rate program, which connects the county's schools via fiber optics. The project aims to connect 2,200 homes in the target region, via 16 base station sites connected to MBC fiber. Though the project's principals have asked the FCC to authorize the use of schools' E-Rate supported fiber as backhaul supporting TVWS at-home connections,[52] separate MBC fibers are being used to connect the base stations until such authorization is granted.[53]

In terms of longer term plans, the project's E-Rate petition indicates that, depending on the success of the initial two-county project, and the result of the petition, "Microsoft and others are planning a second phase of TVWS deployments that could provide access to 40,000 additional students at 183 K-12 schools across rural Southern Virginia."[54]

The initial capital budget for the project is estimated to be \$1.1 to \$1.4 million, depending on final design and coverage areas. The Virginia Tobacco Commission is providing \$500,000 to support the project, with Microsoft and MBC providing the remaining funding, as well as significant in-kind contributions.[55]

Microsoft and MBC began planning the project in the fall of 2015, and placed their first equipment orders in early 2016. The initial hope was to connect the first 100 homes by spring of that year, but software-related connectivity issues led to some delays. As of October 2016, the project had connected roughly 50 customer premise locations via two base stations.

The project is currently deploying the latest version of TVWS equipment from Adaptrum, one of several vendors involved with TVWS from its early development stages. As of October 2016, a range of testing was underway related to coverage and other performance factors, including how these are impacted by use of the higher power levels allowed by the FCC in areas with fewer than 50 percent occupied TV channels,[56] and other technical variables, including antenna height, channel size and aggregation, and product configuration (e.g., whereas most of the current installations used outdoor antennas, testing has been done using indoor devices).[57] According to MBC CEO Tad Deriso, the new Adaptrum gear, combined with higher power and antenna height is resulting in "dramatic improvements in coverage and reliability." These improvements

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[52] Ibid.
[53] Ibid nn. 15, 28.
[54] Ibid n. 16.
[55] Ibid n. 30.
[56] Federal Communications Commission (2015). "Amendment of Part 15 of the Commission's Rules for Unlicensed Operations in the Television Bands, Repurposed 600 MHz Band, 600 MHz Guard Bands and Duplex Gap, and Channel 37, et al." Report and Order in ET Docket No. 14-165 and GN Docket No. 12-268.Adopted Aug. 6, 2015. Released Aug. 11, 2015. ("2015 TVWS Report and Order") At ¶ 1. Available at https://www.fcc.gov/document/fcc-adopts-rules-unlicensed-services-tv-and-600-mhz-bands.
[57] Adaptrum, Inc. "Virginia TVWS 'Homework Gap' Project FCC Experimental License Application Overview." Experiment License Request. www.fcc.gov. Available at https://apps.fcc.gov/els/GetAtt.html?id=179331&x=.

notwithstanding, reception remains a challenge, particularly for indoor devices, which, when effective, can dramatically reduce installation costs.

In general, Deriso reported “pretty good connections” within 2-3 miles of a base station. And whereas he pointed to a successfully connected home six miles from a base station, he also noted that a home located in a hollow two miles from a base station could not receive an adequate signal. Based on speed tests of the current set of TVWS-connected homes, Deriso said that download and upload speeds in the 3-6 Mbps range are “fairly consistent.” Total throughput per base station is in the 100 Mbps range, a capacity that’s split between three directional antennas per base station.

As with the Albemarle K-12 EBS-based project discussed earlier in this section, the online content this project makes available to students at home is filtered in the same way as the content they access at school. But, unlike EBS spectrum, TVWS is not restricted to use for “educational purposes.” This raises the possibility that networks using TVWS to bridge the homework gap could also be used to deliver one or more tiers of commercial Internet access. Deriso, who stated that his company plans to remain a wholesale rather than retail provider, noted that MBC has discussed such possibilities with ISPs it works with, but has yet to finalize any plans. He also acknowledged that moving in this direction could raise regulatory questions needing further clarification from the FCC related to existing programs such as E-Rate and Lifeline.

Though it was in early stages of development during our research, we consider this project significant and worth of further study in relation to its policy, economic and technical elements. In terms of policy, it is exploring a TVWS-based last mile model with potential to help address the homework gap, while also raising new and important regulatory questions (which has already been done via an E-Rate waiver petition). In terms of technology and economics, it is notable relative to other U.S. TVWS deployments in its use and testing of newer generation TVWS equipment, as well as the relatively ambitious scale of both its current two-county plan and its longer term plans.

Lessons and Insights

1. The NMU/Merit project is groundbreaking in its use of the full set of EBS channels (5 channel blocks of 22.5 megahertz each) to deliver LTE-based services to the educational community in a very large, sparsely populated and underserved area.

   Though much of the EBS band has been licensed in major markets (and in many cases leased to commercial entities such as Sprint), much of it remains unlicensed in more rural areas. For example, as Figure 4 shows, a substantial amount of EBS spectrum has yet to be licensed in much of the northern part of Michigan's Lower Peninsula (as discussed in the accompanying regulatory analysis, we note that the table is only an approximation, as EBS is currently not licensed at the county level).

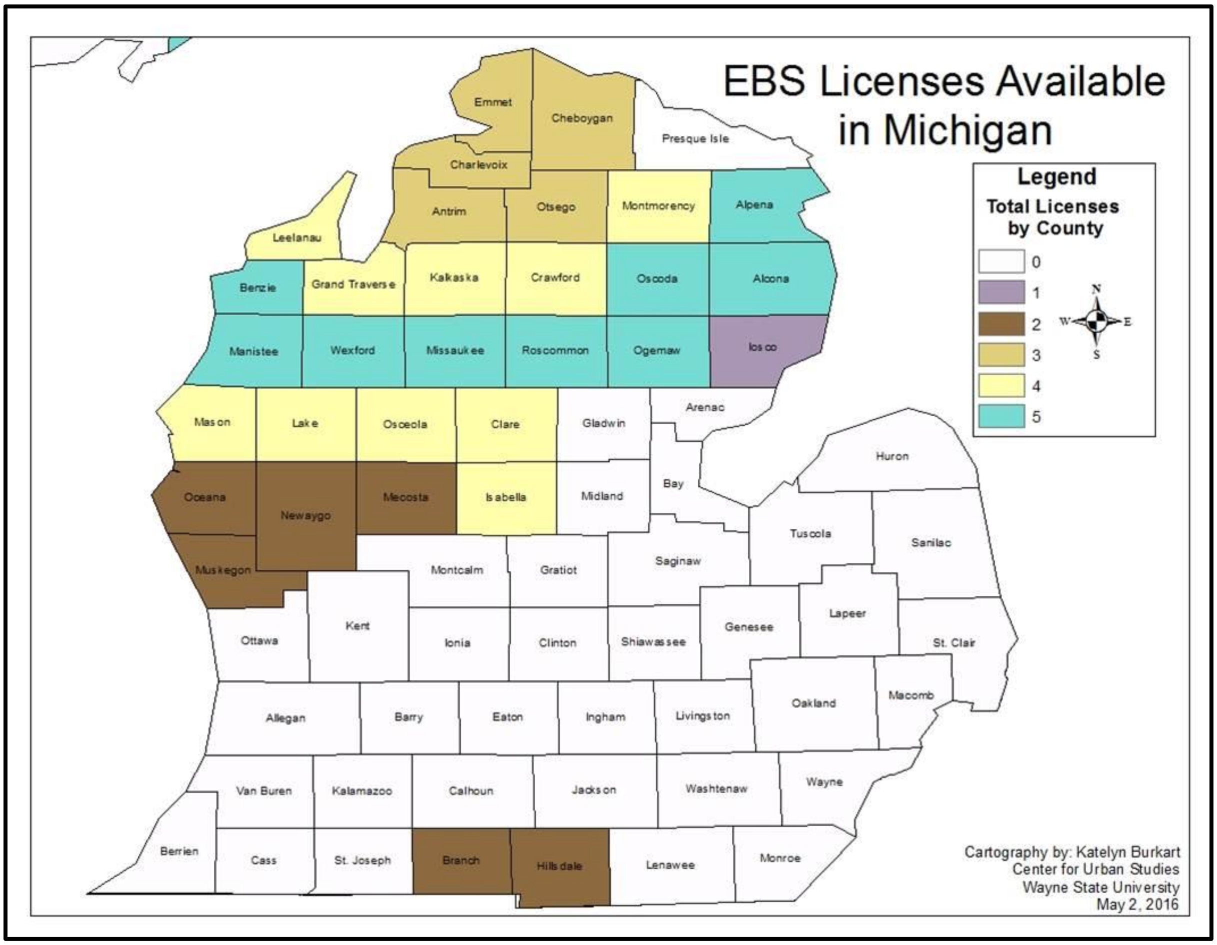

Figure 4: EBS Channels Available in Michigan's Lower Peninsula[58]

[58] Figure courtesy of Patrick Gossman, Deputy CIO, Research and Community, Wayne State University. Original image included in Merit Member Conference 2016 presentation entitled, "4G LTE Broadband for the Last Mile: Spectrum Availability, Performance, Partnering vs. Building Your Own Network." Referenced at https://www.merit.edu/mmc-agenda-detail/#4g-lte.

On one hand, Figure 4 makes clear that here is no unlicensed spectrum in most of the Lower Peninsula, particularly its more populated areas. But, at the same time, it shows that all five 22.5 megahertz EBS channels have yet to be licensed in nine counties, with four channels (90 megahertz) available in another ten counties and three channels 67.5 megahertz not yet licensed in five additional counties. Moreover, as Figure 5 illustrates, Merit has a significant fiber backhaul footprint in most of these counties.

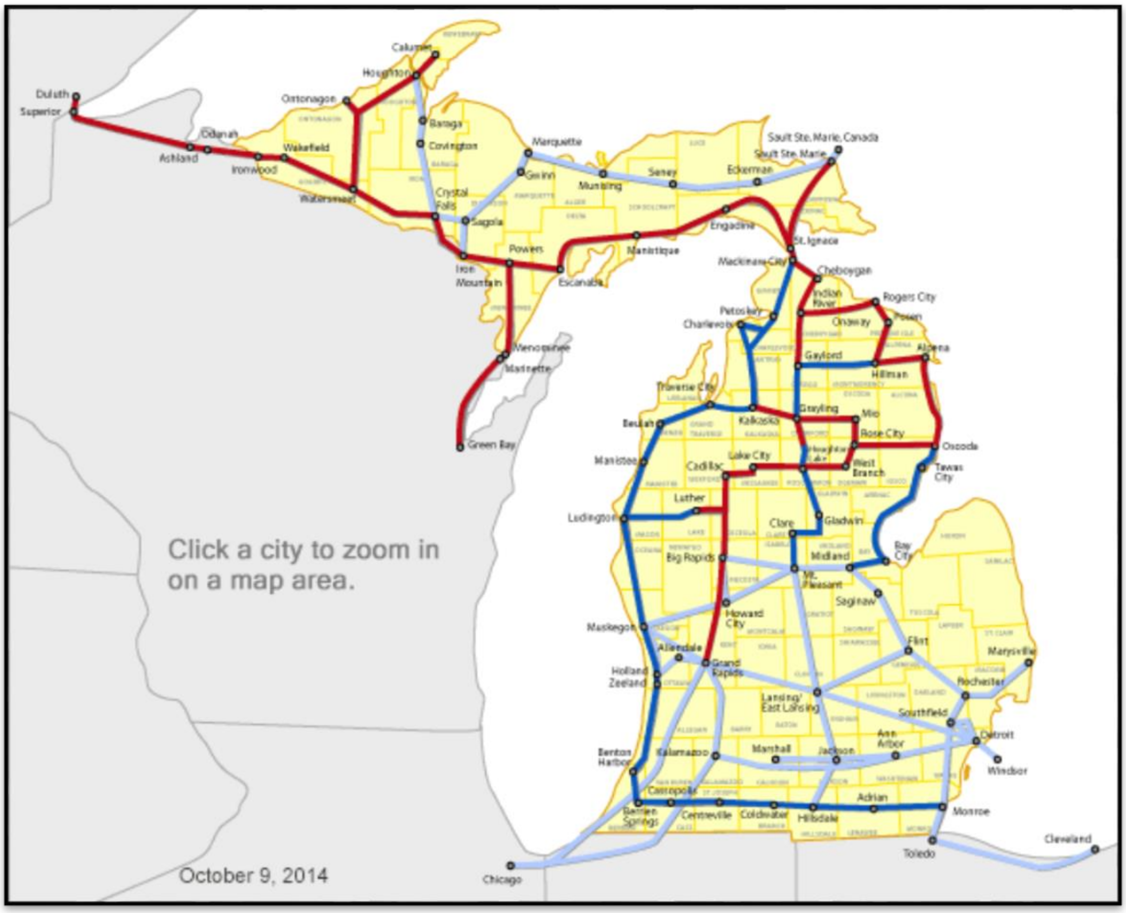

Figure 5: Merit Network Fiber[59]

As an alternative point of reference, the Albemarle case—where the school district currently has access to only 22.5 MHz of EBS spectrum—highlights the fact that some areas and school districts facing serious homework gaps do not have access to the full array of EBS licenses. And though the Albemarle school district aims to expand its EBS spectrum as nearby EBS commercial leases expire, this situation adds not only a current constraint on network capacity, but also a source of uncertainty in terms of planning for future expansion of connections and speeds.

[59] Merit Network. REACH-3MC Project Updates. www.merit.edu. Available at https://web.merit.edu/meritformichigan/progress/index.php.

The homework gap project targeting rural Charlotte and Halifax counties provides a third point of reference because it utilizes TVWS rather than EBS spectrum. As noted at various points in this report, TVWS equipment remains far less mature than EBS based LTE equipment. And, as an unlicensed band, TVWS is more vulnerable to unpredictable interference-related issues. At the same time, however, these two Virginia counties highlight the substantial amount of TVWS spectrum available in many of the nation's rural areas. According to Google's Spectrum Database,168 MHz of TVWS is available for fixed device use in Keysville, VA, Charlotte's county seat, with 114 MHz available in the city of Halifax, the self-named county seat of Halifax County.[60]

2. The NMU/Merit project is potentially groundbreaking in terms of setting a precedent for potential future FCC waivers that could free up previously unlicensed EBS spectrum for use by the educational community.[61] We speculate that that although prospective EBS licensees in areas of the U.S. where an EBS license has not yet been granted need to file a waiver to procure an EBS license, those applicants similarly situated to NMU and seeking to offer an education based service that meets EBS requirements—as opposed to leasing the license for commercial purposes—can reasonably expect to obtain a license upon making a sufficient showing of their intent and capability.
3. In addition to its geographic scope, the NMU/Merit project's institutional scope is also significant, as it is expected to enable other higher education and K-12 institutions to use the network and service management software platform developed by NMU. And though schools are the project's primary focus, it may, over time, lead to an exploration of the definitional boundaries of "educational purpose" associated with the use of EBS spectrum to the extent that there is demand from non-school Community Anchor Institutions (CAIs) such as healthcare facilities and government agencies.
4. The use of LTE technology allows the NMU/Merit and Albemarle County projects and other EBS-based network initiatives to leverage many of the performance and cost benefits driven by the massive global market for LTE network equipment and customer premise equipment (CPE). At the same time, such projects' relatively small volumes have yet to attract strongly competitive dynamics among equipment vendors in terms of developing low-priced products targeted specifically to the EBS spectrum and education-focused market.
5. Though the NMU/Merit service will have significant limitations, including a lack of roaming agreements, increasing availability of dual-SIM devices will help to minimize the negative impacts of these limitations, because users will be able to use their device to access both the NMU/Merit network and cellular networks.

[60] TVWS spectrum availability checked Oct., 23, 2016, by entering city name and press Search button at: https://www.google.com/get/spectrumdatabase/channel/.

[61] A 2014 table showing unlicensed/available EBS spectrum (highlighted in green) by county and channel, submitted by a number of parties together with a "consensus proposal" to license remaining EBS is available at: https://ecfsapi.fcc.gov/file/7521245412.pdf. See the accompanying regulatory analysis for additional discussion regarding the consensus proposal.

NMU and Merit are also exploring the possibility of what might be called an "internal private network" roaming feature, in which individuals affiliated with other Merit member (e.g., students enrolled in other state colleges in MI) are able to access the LTE network when they visit the Upper Peninsula.

6. Because they will operate as private networks that support content filtering (e.g., for K-12 students, as is done in schools), it seems likely that the NMU/Merit and Albemarle networks will not be subject to network neutrality, which allow them to block bandwidth-intensive entertainment services that could interfere with education-related services, especially during primetime hours, when both types of applications may experience peak usage levels. This exemption from net neutrality requirements could, however, be lost were an EBS education-focused network to "go public" (e.g., through roaming agreements).
7. The combination of an EBS-based education-focused network and the NMU (and Albemarle County) policy of providing students with a free laptop, points in the direction of an increasingly universal and standardized system with potential to generate both administrative efficiencies (e.g., distributing the laptops with EBS/LTE SIM cards and software pre-installed) and educational benefits (e.g., fully bridging the "homework gap" for students lacking sufficient at-home access).
8. Both the NMU/Merit and Albemarle projects highlight the value of working with municipalities and public safety entities to develop cooperative arrangements that support relatively low-cost antenna siting strategies. An even broader and more organized effort in this direction is suggested by the effort by a number of northeastern Michigan counties, with assistance from the Northeast Michigan Council of Governments (NEMCOG), to cooperatively develop a vertical asset inventory to help wireless service providers in these counties reduce their network costs by leveraging existing structures like water towers, barns, grain elevators, etc.[62]
9. Both the NMU/Merit and Charlotte/Halifax projects highlight the value for academic institutions of working with middle-mile fiber providers that can help ensure their wireless last mile connections are supported by high-capacity backhaul, and can also contribute other assets and expertise to a project focused on extending last mile broadband connectivity. In the case of the former, NMU is a member/owner of Merit, which is cooperatively owned by the state's major institutions of higher education. In the latter case, Mid-Atlantic Broadband is a non-profit provider of wholesale fiber with a longstanding focus on supporting economic development in the southern Virginia region.
10. It remains unclear the extent to which the FCC's new E-Rate policy will allow E-Rate funded fiber connections at schools to provide backhaul support for "homework gap" projects using either EBS or TVWS spectrum to provide remote access to students, faculty and staff. This issue was raised in a recent FCC

[62] Frederick, E. (2016, Oct. 13). "Closing Dead Zones Without Radio Towers," Blog // Connect Michigan. Available at http://www.connectmi.org/blog/post/closing-dead-zones-without-radio-towers.

Public Notice dated September 19, 2016,[63] which considered two petitions the Commission had received on this question, including one filed by the entities involved in the Charlotte/Halifax county project.[64]

11. Because, unlike EBS spectrum, TVWS is not restricted to educational uses, a homework gap project using it will likely have more flexibility than one using EBS spectrum in terms of combining an education-focused (and perhaps content-filtered) connectivity service with Internet access offerings that might provide faster speeds and unfiltered content provided by commercial ISPs. Such arrangements may raise policy questions not yet fully addressed by the FCC, with regard to E-Rate and Lifeline subsidies and perhaps other regulatory issues.

Implications and Considerations for RENs

1. The relevance of the NMU/Merit and Albemarle projects for other RENs will depend in large part on the availability of unlicensed EBS spectrum within or near their service footprints, something likely to vary considerably by state and within-state region. Similarly, the relevance of the Charlotte/Halifax county project will depend on the availability of TVWS spectrum in geographic areas of interest to RENs.
2. This variation notwithstanding, RENs in other states are likely to learn useful lessons from a careful study of the NMU/Merit, Albemarle and Charlotte/Halifax projects and ongoing consultation with the individuals and organizations involved.
3. To the extent that the service areas of other RENs are associated with significant amounts of unlicensed EBS spectrum, it may be advisable for them to collaborate—perhaps through the Quilt national association—in efforts to move the FCC toward a resumption of licensing and/or expansion and further clarification of the waiver model it applied to the NMU case in Michigan's UP.

   One element of such a collaboration might entail the development of a county or sub-county level dataset tracking the availability of EBS spectrum across the nation in relation to unmet connectivity needs as reflected in Census Block-level FCC broadband availability data and granular Census demographic and Internet adoption data.[65] This database might be even more useful if it included a geographic layer showing the availability of TVWS spectrum. Potential data sources for developing this type of integrated multilayer dataset include FCC databases and FCC-approved TVWS databases managed by private companies.[66]

[63] 2016 E-Rate Public Notice, supra n. 27.
[64] 2016 E-Rate Petition. Supra n. 27.
[65] For adoption data, see for instance, Center for Policy Informatics. Data Access. Arizona State University, Center for Policy Informatics. https://policyinformatics.asu.edu/. Available at https://policyinformatics.asu.edu/broadband-data-portal/dataaccess.
[66] For example, see data download options for Google Spectrum Database at https://www.google.com/get/spectrumdatabase/data/.

Expanding Connectivity Between and Around Campuses

This section includes a case study focused on connecting multiple college campuses with gigabit links and a second project that provides students with broadband connectivity at campus transit locations.

The inter-campus connectivity case study examines a situation in rural New Jersey, where expanding bandwidth demand at its remote campuses has led Brookdale Community College, working with the state's REN, NJEdge, to consider options for connecting these campuses to its fiber-connected main campus with gigabit links ranging in length from 11 to 18 km. Based on information provided by NJEdge, we identified at least one fixed microwave solution likely to achieve this goal at costs well below those involved in deploying fiber to the remote campuses.

Our research team selected the Brookdale situation as one of our case studies in large part based on discussions with NJEdge and other RENs suggesting that demand for inter-campus gigabit connectivity is increasing for educational institutions around the country, but is often lacking for schools that, like Brookdale, are located in relatively rural areas with few affordable options for linking remote campuses with gigabit-level capacity.

The second case considered in this section involves the use of TVWS for backhaul links connecting Wi-Fi hotspots that provide broadband connectivity to students, faculty and staff at transit stations on the campus of West Virginia University (WVU). This project marked the first TVWS deployment by a U.S. university and was undertaken in cooperation with AIR.U, a consortium of educational associations, public interest groups and technology companies whose goal is to deliver wireless broadband applications to underserved campuses and their surrounding communities.

Like other pioneering TVWS projects discussed in this report, the WVU deployment experienced reliability and other performance issues. In addition, its plans for expanding beyond the transit station hotspots and purchasing newer generations of equipment were stymied by state and university-level budget cuts. Nevertheless, it did enhance connectivity for students using the WVU transit system, while also providing proof-of-concept support for similar uses of TVWS, especially as the technology continues to mature.

Case Study: Brookdale Community College and NJEdge considering wireless for gigabit backhaul between campuses[67]

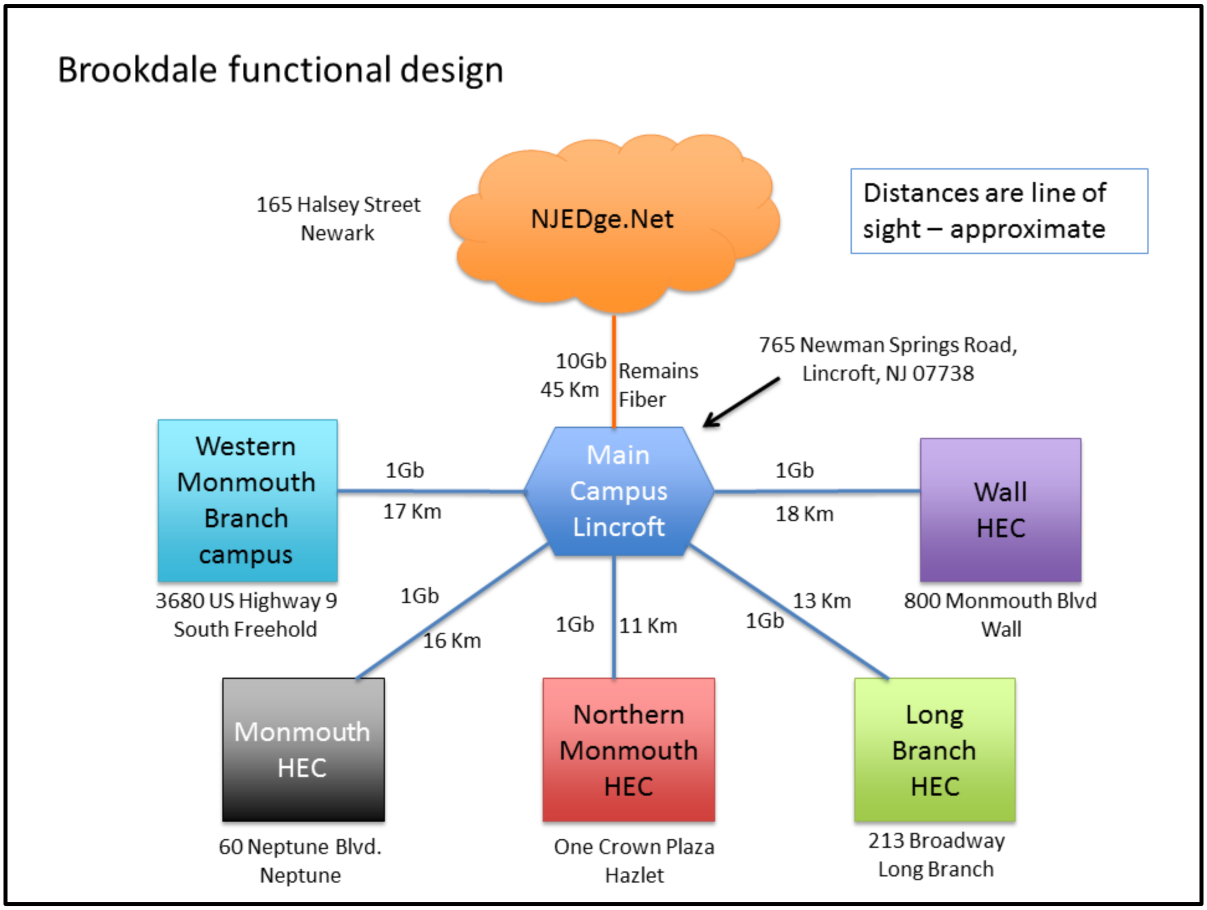

Figure 6: Brookdale Functional Design[68]

Brookdale Community College is among the more than 50 organizations that obtain Internet and Internet2 connectivity from NJEDge.net.[69] This institution serves nearly 15,000 enrolled students.[70] The majority of students attend the main campus in Lincroft while others attend one of the five remote sites which are referred to as Higher

[67] This case study is largely informed by the authors' interviews with representatives at NJEDge involved in wireless expansion at Brookdale, including Ed Chapel, Senior VP (phone interview on Jul. 28, 2016); executives at CostQuest Associates (phone interview on Sep. 7, 2016); and Michael Hutter, Head of National Wireless Sales at MapleNet Wireless (phone interview on Aug. 17, 2016). It was also informed by interviews with ISPs and equipment vendors referred to elsewhere in this report.
[68] Figure courtesy of NJEDge.
[69] See Appendix 1.
[70] Quilt/Quello Center Project – NJEDge Use Case provided by Ed Chapel ("Brookdale Use Case"). This document was used by Ed Chapel to supplement our interview discussion. See also, Brookdale Community College. About the College. https://www.brookdalecc.edu/. Available at https://www.brookdalecc.edu/about/about-the-college/.

Education Centers (HECs).[71] The Lincroft campus is served by NJEDge's fiber backbone (see Figure 6), and was, at the time of our interview with NJEDge, in the process of a backbone infrastructure upgrade and Wi-Fi infrastructure expansion intended for on campus hotspots.

There has been enrollment growth and notable physical plant investment in the HECs, with the most recent being the construction of a STEM Center at the Wall HEC which is approximately 18 km distance from the main campus.[72] Brookdale's strategic plan contemplates much greater cross use of the main campus and the HECs as well as remote access of the instrumentation and instruction that originates at the Wall HEC with its STEM programming.[73] All of these plans specify a minimum bandwidth service among the six locations of 1Gbps (see Figure 6).[74]

NJEDge has determined the costs of connecting the HECs using fiber, but based on the cost, is exploring potential wireless alternatives that could offer 1 Gbps backhaul capabilities. In the present circumstance, achieving a full gigabit of service to all five HEC's using fiber would require a very expensive 10Gb Switched Ethernet Services circuit for aggregation of these remote sites.[75]

Moreover, although there are incumbent service providers that could potentially provide an alternative source of connectivity, Brookdale's remote locations span the service areas of two different cable multiple-systems operators (MSOs), which limits the college's ability to procure a cost effective single-vendor solution from cable providers.[76] Additionally, because of the geographic locations of the main campus and HECs, Brookdale has not benefited from the build out of alternative, facilities based competitive providers with whom NJEDge does business, including Sunesys, Lightower and Cross River.[77] As a result, Brookdale's only existing option for a single carrier solution that serves all of its locations is the local ILEC, Verizon NJ.[78] This is very limiting from a cost/value proposition perspective and, in terms of speed, is limited to 100 Mbps.[79]

As part of our research into wireless alternatives, we explored a number of potential wireless alternatives. Speaking with representatives from Axiom, CostQuest, Cruzio, and MapleNet, each of which had experience evaluating alternative wireless backhaul solutions, we determined that although various approaches could be used to satisfy Brookdale's needs, the standard wireless approach taken in this circumstance is to use fixed microwave service backhaul, the technical and regulatory details of which are covered in substantial detail in the accompanying regulatory analysis.

For a greenfield deployment, the appropriate comparison is the total per mile cost to run fiber with the cost of all links in a wireless solution, including site identification,

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[71] Brookdale Use Case.
[72] Ibid.
[73] Ibid.
[74] Ibid.
[75] Ibid.
[76] Ibid.
[77] Ibid.
[78] Ibid.
[79] Ibid.

acquisition and development, permitting, and licensing. A rough estimate for a fiber extension obtained from our interviewees, which does not necessarily apply to the Brookdale case, is $25,000 per mile of fiber, with an additional cost of approximately $5,000 per node (end) for Ethernet link equipment.

In contrast, assuming an existing tower or other structure to support it, an estimated cost range for a fixed microwave link, including comparable endpoint Ethernet costs, would be in the $50,000 to $75,000 range. These figures should be taken as general guidelines because, as with fiber, there can be substantial variability in real-world costs for wireless links.

Beyond the cost of equipment, the costs of link setup can vary widely depending on the situation. This can vary from installing a new tower at the high end of the cost range, to the costs associated with making an existing site (e.g., tower or rooftop) capable (e.g., in terms of structure and power) to support the necessary antenna (which can vary considerably in size and weight based on frequency, interference risks and other factors) and related equipment.

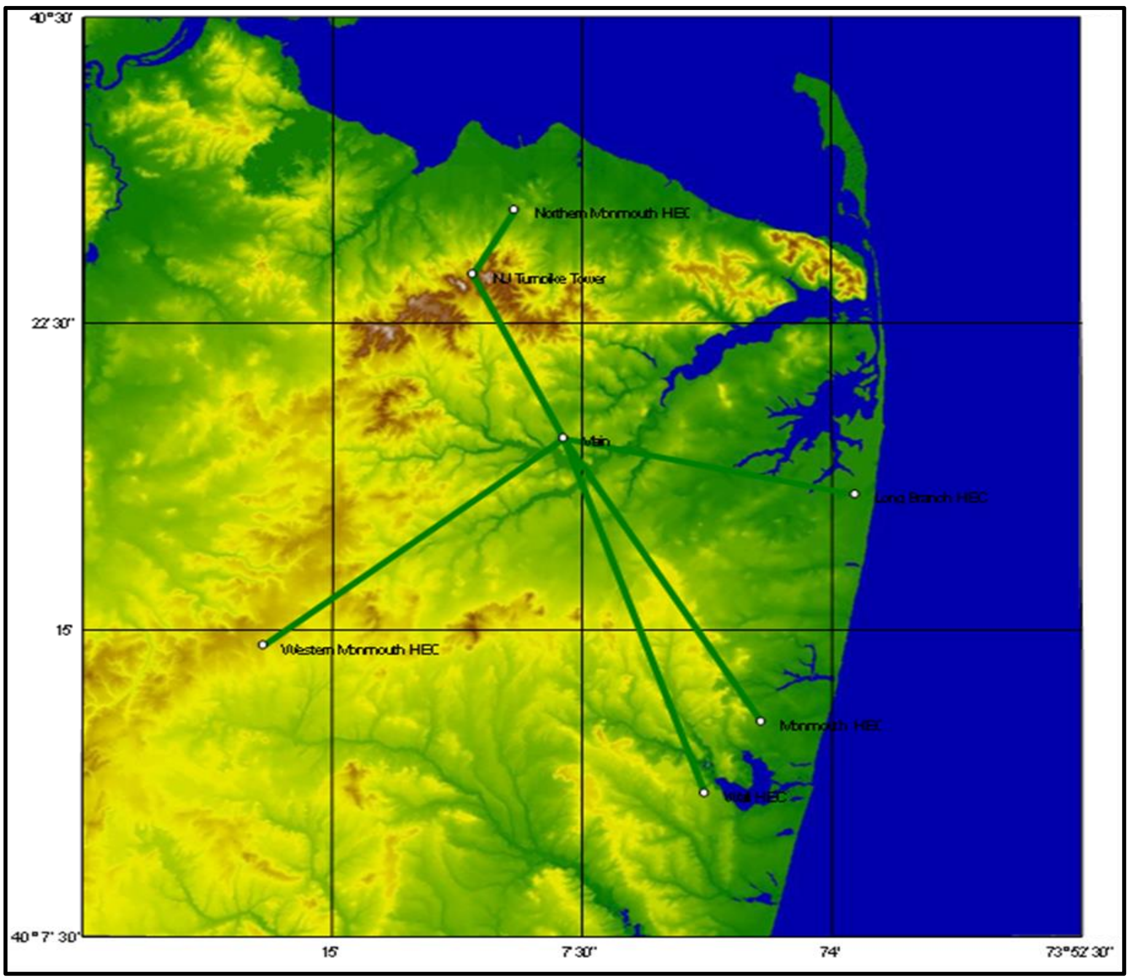

Figure 7: Fixed Microwave Design Concept

In addition to our interviews above, we asked a value added reseller (VAR) that has previously worked with RENs to review the Brookdale situation as described above, and to provide a preliminary design (see Figure 7) and cost estimate for a potential solution. Although we could not provide the VAR with sufficient details to provide us with a more definitive design and estimate, its input shed helpful light on what might be involved.

The proposed design was a hub and spoke architecture that did not use any of the remote sites as repeaters feeding other sites, an approach that, in some cases, can reduce costs. It also did not take into account local and state zoning and permitting for towers, something that would require additional investigation.

The proposed network employed 11 GHz licensed microwave links and, as required by Brookdale and NJEdge, was designed to deliver 1 Gbps speeds from the main campus to each remote HEC. It employed 4 foot antennas and, due to line-of-sight restrictions, getting the signal to the Northern Monmouth HEC required a two-hop link, as illustrated in Figure 7. We note that for "long-haul" links such as these, different interviewees differed in their preferred spectrum bands (e.g., some preferring 11 GHz spectrum and other 18 GHz spectrum), which was likely driven in part by the different markets that they typically serve. For example, Axiom, an ISP whose service area spans a geographically expansive but sparsely populated rural area, cited use of 11 GHz for its point-to-point links, while Cruzio, operating in an urban market where link distances tend to be shorter, described 18 GHz as its preferred frequency band for point-to-point links longer than two miles.

Example: West Virginia University using TVWS as backhaul for Wi-Fi hotspots at campus transit stations

In July 2013, West Virginia University (WVU) became the first university in the United States to use TVWS spectrum to expand broadband connectivity on its campus. It did so through a partnership with AIR.U, a consortium of educational associations, public interest groups and high-tech companies aiming to deliver wireless broadband applications to underserved campuses and their surrounding communities.[80]

The network is managed by AIR.U co-founder, Declaration Networks Group,[81] and is a collaboration[82] between AIR.U.; the WVU Offices of Research and Information Technology; the West Virginia Network for Telecomputing,[83] which provides fiber backhaul for the network; and Adaptrum, which supplied the TVWS equipment.[84]

According to Steve Belcher, WVU's Assistant Director of Network Operations, the network serves WVU's five Personal Rapid Transit (PRT) stations, with TVWS providing backhaul from a fiber-connected location to Wi-Fi hotspots that provide user connections at the transit stations.[85]

During the school year, approximately 15,000 people ride the PRT each day.[86] According to Belcher, PRT faced expanding demand for capacity and coverage that could not be met by the DSL service that was its only practical and affordable backhaul option for connecting the transit stations. This led the university to consider TVWS as an alternative. After being approached by AIR.U, WVU agreed to undertake a proof of concept deployment.

In a statement published on the AIR.U website, WVU's CIO John Campbell expressed the broader vision behind the AIR.U consortium and the WVU pioneering project:

> *"Not only does the AIR.U deployment improve wireless connectivity for the Public Rapid Transport System, but it also demonstrates the real potential of innovation and new technologies to deliver broadband coverage and capacity to rural areas and small towns to drive economic development and quality of life, and to compete with the rest of the world in the knowledge economy."*[87]

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[80] AIR.U. The AIR.U Initiative. www.airu.net. Available at http://www.airu.net/about/; Williams, T.P. "Air U: Transforming TV White Spaces into Internet Connectivity" AIR.U. Available at http://www.airu.net/transforming-white-spaces/.

[81] Declaration Networks. http://www.declarationnetworks.com/.

[82] Transforming "TV White Spaces" Frequencies into Connectivity for Students and the Surrounding Community, ACUTA Fall Conference Oct 2013.

[83] West Virginia Network. About. www.wvnet.edu. Available at http://wvnet.edu/about/.

[84] Adaptrum. http://www.adaptrum.com/.

[85] August 15, 2016 phone interview with Steve Belcher; West Virginia University. Transportation and Parking. Personal Rapid Transit (PRT). http://www.wvu.edu/ Available at http://transportation.wvu.edu/prt.

[86] West Virginia University. Transportation and Parking. PRT Facts. http://www.wvu.edu/ Available at http://transportation.wvu.edu/prt/prt-facts.

[87] AIR.U. Quick Start Program. www.airu.net. Available at http://www.airu.net/quickstart/.

While our research suggests this vision has real merit, it appears that the combination of large funding cuts at the state and university level, coupled with the limitations of the project’s early generation TVWS technology, has at least delayed the WVU TVWS project’s evolution toward that vision, leaving WVU, as Steve Belcher put it, “on its own and presently trying to update antennas.”

Lessons and Insights

It's very preliminary nature notwithstanding, the VAR-provided network design and estimate for the Brookdale connectivity case is helpful in understanding the cost of deploying gigabit-speed wireless links in relation to comparable fiber costs and in terms of its key components. For example:

1. Excluding tower-related costs, the average per-link cost, including radios, labor, license-related costs, antennas, cable, grounding) was in the $40,000-$45,000 range. Taking the double-hop link required to connect one of the HECs into account, the average was roughly $52,000 per HEC, or $260,000 in total.

   These costs would compare to average per-HEC costs and total costs to connect the HECs via fiber of approximately $233,000 and $1.17 million, respectively, assuming an average cost for fiber links of $25,000 per mile.[88]

2. The cost of installing towers of the heights necessary to support line-of-sight transmission (which ranged from 100 to 220 feet based on 65 feet assumed tree height), was substantially higher than the cost of the wireless links themselves, totaling approximately $423,000, or $84,600 per HEC.

   If we assume these tower costs (which are effectively worst case cost assumptions), the total cost for the 1 Gbps wireless links increases to $683,000 ($136,600 per HEC), still well below the estimated $1.17 million total costs to connect the HECs via fiber.

   Though actual tower-related costs might be substantially lower than this preliminary estimate (which did not take into account the possibility and cost of suitably tall existing antenna-siting space), this "from scratch" tower cost estimate highlights the potential significance of this component of wireless costs.

Implications and Considerations for RENs

1. Our review of the VAR's preliminary design and cost estimate highlights the potential of point to point microwave links to provide substantial cost savings relative to fiber for situations involving speed (1 Gbps) and distance (11-18 km per link) requirements similar to the Brookdale remote campus case.
2. It also highlights the significance of tower-related costs in the total cost equation for high-capacity, long-distance, line-of-sight-dependent wireless links, whether these costs are capitalized (as might be the case if tower construction was required) or are included as operating expenses associated with leasing tower space.
3. The potentially large cost impact of tower related capital and/or operating expenses highlights the value of antenna-siting strategies discussed in our NMU/Merit and Axiom Technologies case studies, where arrangements were made to exchange network capacity and/or other services for all or part of the

[88] Note that a mile consists of approximately 1.61 kilometers.

cost to access to suitably tall structures, such as water towers. To the extent that other RENs are able to make similar arrangements for antenna siting, the economics of their involvement in wireless could become more favorable.

Community Anchor Institutions and Municipalities Using Wireless to Extend and Enhance their Services

This section of the report contains one case study and four examples. The case study focuses on one of the first and best-documented projects supported by the Gigabit Libraries Network's (GLN) White Space Project, undertaken by the public library in Manhattan, Kansas. The main purpose of the project was to use TVWS equipment to extend the library's offering of public Internet access beyond its physical walls. Though, like other pioneering TVWS deployments, the project experienced some technical challenges, the hotspots it deployed proved popular, exceeding in-library usage during the summer months. The project's success also led the library staff to discuss with local government agencies the TVWS network's potential to support local emergency communications, though funding to pursue this possibility was not available.

Public safety was also a key focus of three of the examples discussed in this section. For example, in North Carolina, the city of Wilmington and New Hanover County used TVWS for multiple purposes, including video surveillance and public-access Wi-Fi hotspots at public parks, perimeter monitoring at a detention facility, and remote monitoring of road conditions and water quality.

In Fort Myers, Florida, the city government, following a shooting at a popular local event, invested in a video surveillance system in the downtown area that included 49 4k-quality high resolution cameras connected by a 60 GHz (V-band) millimeter wave network that not only supported the required bandwidth, but had a physical footprint suitable for a multi-site urban deployment (as indicated by the photo included in our discussion of this case).

Though texting-friendly community-service applications such as a digital message board and bus-status information were its initial purpose, emergency communications turned out to be a high-value application for another of our network examples: Red Hook WiFi, a Wi-Fi mesh network developed by a local non-profit, Red Hook Initiative (RHI),[89] in partnership with New America Foundation's Open Technology Institute (OTI),[90] and managed and maintained by Digital Stewards, OTI-trained young adult residents of the Red Hood area. During and after Hurricane Sandy, which in 2012 hit the area very hard, the Red Hook mesh network proved itself to be a useful and flexible emergency communication resource. The potential relevance of such networks to support community resilience in emergencies was acknowledged a few years after Sandy struck, when OTI was awarded a "RISE: NYC" grant from the New York City Economic Development Corporation to expand the OTI/Red Hook model in selected areas within all five of the city's boroughs. [91]

The final example in this section involves a rural telemedicine application delivered via a TVWS network in a rural area of Botswana. Though located outside the U.S., we

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[89] Red Hook Initiative. http://rhicenter.org/.

[90] New America. Open Technology Institute. About Us. www.newamerica.org. Available at https://www.newamerica.org/oti/about-us/.

[91] New America (2015, May. 1). NYC. "New America's Resilient Mesh Wireless Project Wins RISE: NYC Competition." Available at http://www.newamerica.org/nyc/press-releases/new-americas-resilient-mesh-wireless-project-wins-rise-nyc-competition/.

included this case because the basic dynamics of connecting rural health clinics to medical specialists located at urban centers has relevance to rural areas in the U.S., especially tribal areas, which often lack the access to medical expertise enjoyed by residents of urban areas. As this case suggests, telemedicine applications using affordable network technology capable of supporting the required applications and bandwidths, have potential to reduce patient and healthcare system costs (in both money and time), while also improving health outcomes.

Case Study: Manhattan Kansas Public Library and Gigabit Libraries Network extending library-provided Internet access via TVWS-fed Wi-Fi hotspots[92]

Description

The Gigabit Libraries Network (GLN) is a collaboration of libraries intended to provide a distributed testbed and showcase for high performance applications and equipment in the service of educational, civic and cultural objectives.[93] Its principal is Don Means, who also heads up GLN's White Space Pilot project. Working with the leading TV White Space (TVWS) equipment vendors, GLN invited libraries to undertake pilot projects utilizing TVWS technology. The goal was to assess TVWS as a tool for expanding public library Wi-Fi availability and overall community connectivity, and possibly providing an additional resource to support disaster readiness.

TVWS, which operates on an unlicensed basis in unused channels in the very high frequency (VHF) and ultra-high frequency (UHF) television bands, has some notable strengths as a tool for bridging remaining gaps in broadband availability.[94] These include relatively strong propagation characteristics compared to higher frequency bands that are more dependent on line-of-sight connectivity. Another potential strength is that available TVWS channels tend to be more abundant in rural areas, as suggested by the map in Figure 8, developed by a team at UC Berkeley.[95]

Some of TVWS spectrum's propagation strength is, however, hampered by the relatively low TVWS power levels and antenna heights currently authorized by the FCC for TVWS devices. Related to this is the fact that, because TVWS is not licensed spectrum, its usage faces congestion-related risks similar in principle to those faced by today's Wi-Fi devices and spectrum bands (e.g., 2.4 and 5 GHz). As noted in the discussion of the NMU/Merit case study in this report, this interference risk is not present with EBS spectrum, which is exclusively licensed based on a geographic service area (though EBS does not propagate as well as TVWS spectrum).

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[92] This case study is largely informed by the authors' interviews with representatives from Manhattan (Kansas) Public Libraries (phone interview on Aug. 26, 2016); Don Means, a collaborator in the Gigabit Libraries Network (phone interview on Aug. 25, 2016); as well as various TVWS equipment manufacturers and vendors.

[93] The Gigabit Library website is http://www.giglibraries.net/. See also, Gigabit Libraries Network. Libraries WhiteSpace Project. Available at http://giglibraries.net/page-1712342; Digital Village Associates. Projects. Available at http://www.digitalvillage.com/projects.html; Gigabit Libraries Network. Google+ (blog). Available at https://plus.google.com/communities/117593129922934364446.

[94] The VHF and UHF bands are described in additional detail in the accompanying regulatory analysis.

[95] See Harrison, K., and Sahai, A. (2013). Register everyone: on the whitespace use of wireless microphone channels, channel 37, and the soon-to-be guard bands. Wireless Foundations, EECS, UC Berkeley. Mimeo. Several companies manage databases of currently available TVWS searchable by location, including Google (https://www.google.com/get/spectrumdatabase/) and Spectrum Bridge (http://whitespaces.spectrumbridge.com/whitespaces/home.aspx).

As one of the earliest and best documented pilots undertaken under GLN's White Space program, the Manhattan Kansas Public Library TVWS deployment was selected as a case study that shows the potential of TVWS as an extension of the fiber connectivity available to a growing number of public libraries and other CAIs, some of which is provided by RENs and some subsidized by E-Rate funding.[96]

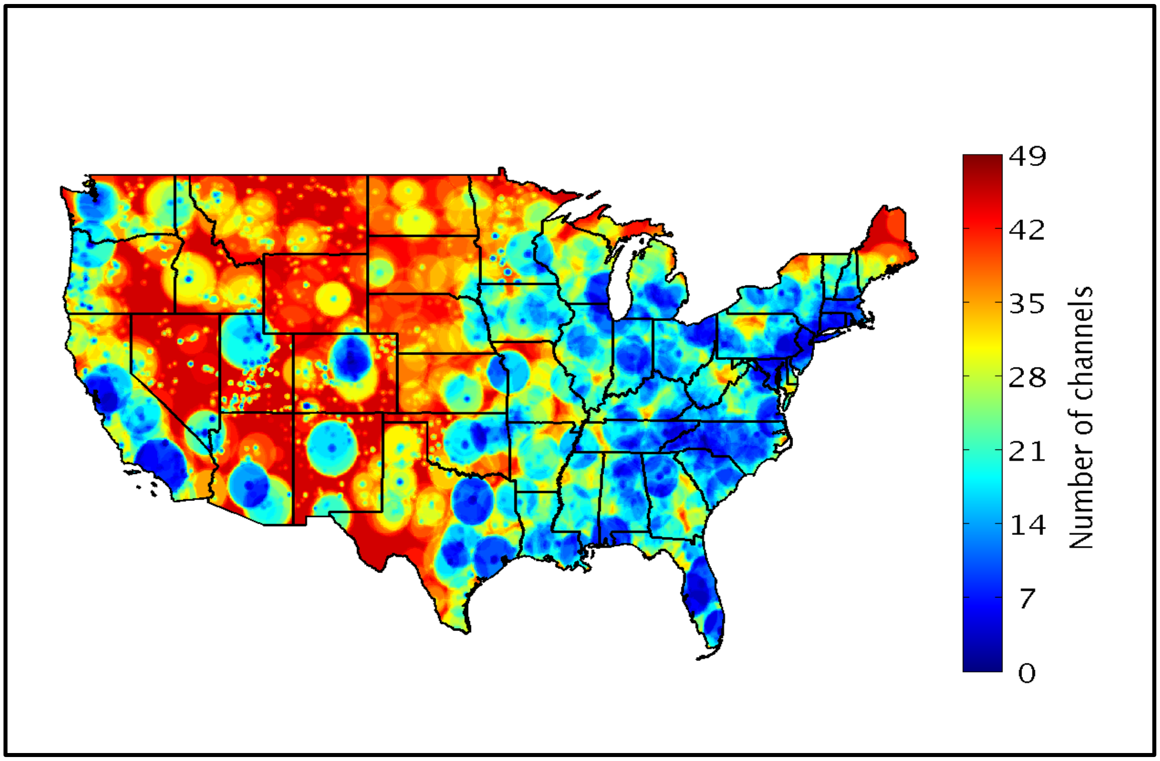

Figure 8: TVWS Channel Availability[97]

The initial Manhattan Library TVWS project involved connecting three public access Wi-Fi hotspots to the library's 100 Mbps public access network via early-generation TVWS equipment provided by Carlson Wireless.[98] One location was at a public park, another was at a community pool (whose equipment was shifted to an ice rink in the winter), and the third was located in a community center in a relatively low income part of the city (see Figure 9). The hotspots were operated as part of the library's public access network and, on average, were delivering 2-3 Mbps connectivity to individual users.

Though the TVWS equipment used in the project was not mature enough for commercial deployment, the library's tech staff of three was able to handle the bulk of installation and troubleshooting tasks in-house. Kerry Ingersoll, the library's Information Technology Manager, described the equipment as "essentially plug and play" and the installation process as "surprisingly quick for new technology." He also indicated that the

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[96] See Ingersoll, Kerry (2015, Jun. 22). "Gigabit Libraries Network." Google+. Available at https://plus.google.com/107631107756352079114/posts/L4Y8ci8sG5Y.

[97] Harrison, K. (2015, May. 15), "A Quantitative Approach to Wireless Spectrum Regulation." Ph.D. Dissertation. Electrical Engineering and Computer Science, UC Berkeley. Figure 2.3(a). Available at https://www2.eecs.berkeley.edu/Pubs/TechRpts/2015/EECS-2015-142.pdf.

[98] See Carlson Wireless Technologies at and http://www.carlsonwireless.com/.

network does not require much ongoing maintenance beyond collecting usage statistics. He said that Carlson provided his team with good support regarding interference issues. And noting that, his staff are "not broadcast engineers," he said the project involved a learning curve, though not a steep one.

After an initial period of operation, the project staff concluded that locating antennas indoors, as was originally done, likely contributed to performance problems, and were in the process of moving these outdoors at the time of our interview. This suggests that, in spite of the relatively strong propagation characteristics of the TVWS band, power limits for TVWS may be contributing to the project's performance problems with indoor antennas.

Though moving the antennas to outdoor locations may significantly improve throughput and coverage using the current-generation Carlson equipment, Ingersoll's comments suggest that the project staff does not yet have a clear understanding of how best to optimize the system aside from moving the antennas outdoors. This suggests that, while getting such TVWS-fed Wi-Fi hotspots operational may not be difficult for a library with a tech-staff of three, optimizing network performance and troubleshooting coverage issues are more challenging, especially when working with early-generation TVWS equipment. To put it another way, whereas the learning curve to get acceptable and beneficial performance may not be steep even with this early-generation equipment, it has proved to be significantly steeper when it came to optimizing network performance. Based on experience with other technologies, this is likely to improve with time, as user experience informs the design of newer generations of TVWS equipment.

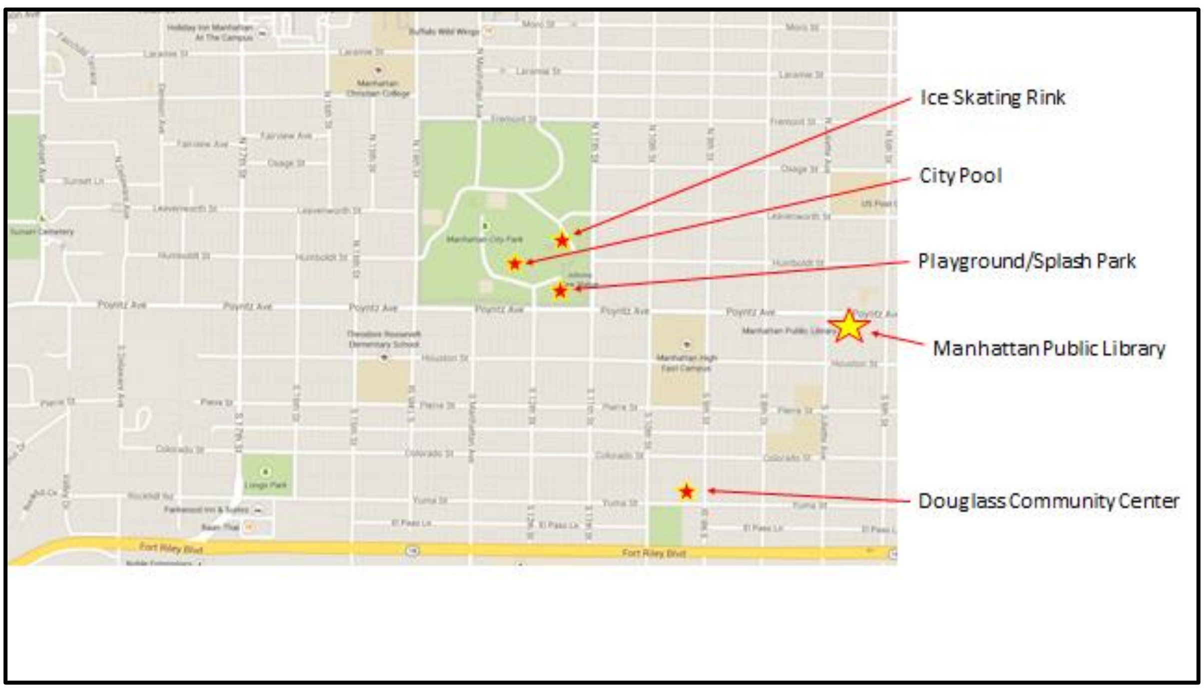

Figure 9: Manhattan (KS) Library Wi-Fi Hotspots[99]

[99] Figure courtesy of Manhattan (Kansas) Public Libraries.

As to the service's popularity, Ingersoll noted that the library-connected community hotspots were fairly heavily utilized, accounting for 37 percent of total library network traffic during colder months and exceeding in-library usage during June-August.

Because it was part of the GLN project, the library received a discount and full refund warranty for the equipment. The total equipment cost came to $6,500, which includes a discount received by the library. That amounts to an average cost of approximately $2,167 per link, a cost expected to decline considerably as Carlson and other vendors introduce new generations of TVWS equipment. Carlson expects to launch its third-generation TVWS system in late 2016 or early 2017 and, though its pricing was not finalized at the time we interviewed Jim Carlson, CEO of Carlson Wireless (phone interview Aug. 30, 2016), he indicated that its per-link cost will be roughly an order of magnitude lower than the $2,167 cost for the first generation equipment used in the Manhattan library project, while also providing enhanced functionality.

Ingersoll said that the library currently has access to two separate 100 Mbps connections, one a fiber connection, the other provided by Cox Communications via cable modem. One is used internally by library staff, the other for public access. He estimated that average use of both networks is in the 20 Mbps range—that is, the library's daily bandwidth usage falls well below its backhaul capacity in terms of serving as an anchor for community access.

Ingersoll also cited the potential value of the community TVWS hotspots to serve as local emergency access points. He said that initial contact with the city and the county's Emergency Management Department about this possibility generated interest in learning about the technology and its potential for use in a crisis situation. But he also noted that there is currently no funding available to support this kind of usage. When interviewed, GLN's Don Means also highlighted this potential, citing the relative portability of TVWS equipment (which will improve further in the future), as well as its relatively unique ability to support non-line-of-sight connectivity, a characteristic that could be important in emergency situations. He also pointed the Quello Center team to a recently funded "SecondNets" project aimed at exploring the potential role of "libraries as second responders in disasters."[100]

To get a more complete picture of the context in which the Manhattan library project takes place, the Quello Center research team also separately interviewed executives from three leading TVWS equipment vendors, along with Microsoft, which has been very active in supporting TVWS pilots and technology development, and individuals involved in TVWS pilot projects undertaken by (i) a university (West Virginia University); (ii) local government (New Hanover County and the city of Wilmington, NC); (iii) two rural Virginia school districts (Charlotte and Halifax counties), working with middle-mile fiber provider Mid-Atlantic Broadband and; (iv) a coalition of organizations piloting a rural telehealth application in Botswana.

[100] Means, D. (2016), supra n. 213.

Example: New Hanover County and Wilmington, NC using TVWS to support public hotspots, video surveillance and other "Smart City" applications

In early 2012, shortly after the FCC's first approval of a TVWS device, the city of Wilmington and surrounding New Hanover County teamed up with multiple companies to launch the nation's first TVWS network. Companies involved in the project included TVWS database provider Spectrum Bridge,[101] TVWS equipment vendor 6Harmonics,[102] and TV Band Service[103] (TVBS), a Wilmington-based company focused on exploring new communication opportunities associated with the switch from analog to digital broadcasting (in 2009 the Wilmington television market had been the first in the nation to introduce digital broadcast technology).

Figure 10: TVWS Links to Security Cameras and Public Access Hotspots at Hugh MacRae Park, Wilmington, NC[104]

The TVWS project served as a testbed for multiple "smart city" applications, including:

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[101] Spectrum Bridge. http://whitespaces.spectrumbridge.com/whitespaces/home.aspx#Search.
[102] 6Harmonics. http://www.6harmonics.com/.
[103] TV Band Service, LLC. http://tvbandservice.com/.
[104] Baker, W. (2015, Mar. 23). "White Space Technology for Wireless Broadband." Slide Presentation, SREB Educational Technology Cooperative. Available at http://publications.sreb.org/2015/WhiteSpaceWebinar.pdf.

- low-cost backhaul to support video surveillance and public hot spots at public parks (see Figures 10 and 11) and the city's Youth Enrichment Zone; [105]
- public access wireless in urban areas;[106]
- perimeter monitoring and communication links for New Hanover County Juvenile Centre;[107]
- monitoring traffic conditions on roads that previously lacked access to a broadband connection;[108]
- using TVWS-connected sensors to monitor water quality in intercostal waterways, tidal creeks and retention ponds used for storm water management, saving the local water department time and money compared to the more labor intensive methods previously used.[109]

As explained by William Seiz,[110] president of TVBS, the TVWS-linked surveillance cameras in the parks, helped reduce the county's insurance costs for the parks, some of which had experienced vandalism problems. The cost of linking the cameras via fiber or other wired solutions was considered prohibitive, as was a mobile wireless solution due in large part to its use of data caps. And because the parks only required standard definition video, the signal could be transmitted using only a portion of a single 6 MHz channel.

Seiz also pointed to what he called the three Cs" of wireless network planning: cost, capacity and coverage." As an example of the tradeoffs that sometimes occur between these three factors, he cited the greater distances that can be achieved in transmitting low-bandwidth sensor data versus those achievable when connecting high-bandwidth applications, including public access Wi-Fi hotspots.[111]

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[105] White Space Technology for Wireless Broadband, March 23, 2015, Slide 14, http://publications.sreb.org/2015/WhiteSpaceWebinar.pdf.
[106] Ibid.
[107] Ibid. Dynamic Spectrum Alliance Worldwide Commercial Deployments, Pilots and Trials, p. 22, http://dynamicspectrumalliance.org/pilots/.
[108] Government Technology (gt) (2013, Aug. 26). "Whatever Happened To . . . White Space Network Products, L.A.'s Gmail Contract, Fingerprint ID Program?" Available at http://www.govtech.com/health/Whatever-Happened-To--White-Space-Network-Products-LAs-Gmail-Contract-Fingerprint-ID-Program.html.
[109] Zager, M. (2010). "Smart City Network Uses TV White Spaces," Broadband Communities Magazine, May-June 2010, pp. 52-53. Available at http://www.bbcmag.com/2010mags/may-june10/BBP_MayJune10_SmartCityNetwork.pdf.
[110] August 18, 2016 phone interview with William Seiz, President of TVBS.
[111] Ibid.

Figure 11: TVWS Linking Security Cameras in Veterans' Park, Wilmington, NC[112]

[112] Baker, W. (2015, Mar. 23). "White Space Technology for Wireless Broadband." Slide Presentation, SREB Educational Technology Cooperative. Available at http://publications.sreb.org/2015/WhiteSpaceWebinar.pdf.

Example: Fort Myers, Florida using Millimeter Wave links to support high-resolution video surveillance system in downtown area

Whereas the Wilmington, NC project discussed above demonstrated that TVWS links could support a modest number of standard resolution video surveillance links, cities seeking to deploy and network larger numbers of higher resolution video surveillance cameras in relatively dense urban areas may find Millimeter Wave (mmW) technology better suited for this purpose. Using Seiz's "three C" framework, it is fair to say that, relative to TVWS, mmW links are superior when it comes to "capacity" but relatively weak when it comes to "coverage."

One example of this is the deployment of mmW links by the city of Fort Myers, FL. That project, announced in August 2016,[113] uses 60 GHz links provided by mmW vendor Siklu, to support a fairly dense network of 49 ultra-high definition 4k security cameras supplied by Axis Communications,[114] coupled with a video management system from IPVideo Corp.[115]

According to an IPVideo press release, the majority of the new cameras deployed in Fort Myers are state-of-the-art, 33 megapixel, 180 degree models, each featuring three separate 4K lenses, which IPVideo president David Antar describes as "10 times more powerful than traditional security cameras." The surveillance network also includes a number of strategically placed HD pan-tilt-zoom cameras that allow system operators to zoom in on any aberrant activity spotted by the super megapixel fixed cameras.[116] The IPVideo management system allows city officials to monitor the cameras live, on mobile devices such as smart phones and tablets.[117]

The city of Fort Myers decided to install the surveillance system following a shooting during Zombicon, a zombie-themed art and music festival, held in October of 2015. A+ Technology & Security Solutions[118] completed the installation in just three weeks to meet the city's deadline of having the system in place for its New Year's Eve celebrations.

According to local news reports, the video surveillance system cost the city between $450,000 to $500,000, or roughly $2,500 per camera.[119]

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[113] Sagi, E. (2016, Sep. 08). "The City of Fort Myers, Fla., Selects Siklu as its Provider of Wireless Connectivity for its City-Wide Video Surveillance System." Siklu Press Release. Available at http://www.siklu.com/city-fort-myers-fla-selects-siklu-provider-wireless-connectivity-city-wide-video-surveillance-system/.

[114] Axis Communications. Safe Cities. www.axis.com. Available at http://www.axis.com/fi/en/solutions-by-industry/safe-cities/products-and-solutions.

[115] IPVideo Corporation. Press Room. "IPVideo Corporation Brings State-of-the-Art City-Wide Surveillance to Ft. Myers, Florida," Jan. 19, 2016. Available at http://ipvideocorp.com/About/News/Article/50/IPVideo-Corporation-Brings-State-of-the-Art-City-Wide-Surveillance-to-Ft-Myers.

[116] Ibid.

[117] Ibid.

[118] A+ Technology & Security. http://www.aplustechnology.com/.

[119] WINK News (2015, Dec. 9). "Surveillance cameras to be installed soon in downtown Fort Myers." Available at http://www.winknews.com/2015/12/08/downtown-fm-surveillance-cameras/;

Figure 12: Networked 4K HD Surveillance Camera in Fort Myers, FL[120]

In addition to their multi-gigabit throughput capacity to support advanced 4k resolution cameras, Siklu's 60GHz radios supported path redundancy to help ensure 24/7 video coverage and, importantly for urban network deployments, they have a relatively small and non-intrusive form factor, as shown in Figure 12.

Greenberg, L. (2016, Mar. 23). "Fort Myers Chief explains how downtown cameras keep you safe," Fox 4. Available at http://www.fox4now.com/news/4-in-your-corner/fort-myers-chief-explains-how-downtown-cameras-keep-you-safe.

[120] Photo sourced from Siklu Aug. 9, 2016 press release, http://www.siklu.com/city-fort-myers-fla-selects-siklu-provider-wireless-connectivity-city-wide-video-surveillance-system/.

Example: Red Hook Initiative and OTI using Wi-Fi mesh network to support community service and emergency communications in a vulnerable urban area[121]

Red Hook WiFi[122] is a community owned and operated Wi-Fi mesh network that provides Internet access in the Red Hook section of Brooklyn, NY. The network, launched in 2011 is supported by backhaul provided by locally owned Brooklyn Fiber.[123]

Red Hook[124] is located in the northwestern corner of Brooklyn, extending out into the Hudson Bay and cut off from the rest of the borough by an expressway. It is home to approximately 5,000 residents of public housing and other low income areas near the expressway. It also includes public parks and industrial sites, and areas in the process of gentrification, with small businesses closer to the water and an Ikea store.[125]

Developed by a local non-profit, Red Hook Initiative (RHI),[126] in partnership with New America Foundation's Open Technology Institute (OTI),[127] the Red Hook WiFi network uses OTI's CommotionWireless[128] firmware running on Ubiquiti routers. Commotion is a free and open-source communication tool that uses mobile phones, computers, and other wireless devices to create decentralized mesh networks that can grow in a relatively dynamic and organic manner as new nodes are added to the network. It is also well suited to host applications on local servers and/or network routers, and does not require a connection to the Internet for neighborhood services to be able to function. In addition to supporting the development of community-focused applications, this also makes the network relatively resilient to outages as long as local power remains available, which occurred during and after Hurricane Sandy and is discussed further below.[129]

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121 Our discussion of the Red Hook WiFi project is based largely on an OTI-published case study published February 1, 2013 (https://www.newamerica.org/oti/blog/case-study-red-hook-initiative-wifi-tidepools/) and an interview with Tony Schloss, Director of Media Programs at RHI, and Jonathan Baldwin, a designer who began work on the network while a masters candidate at Parsons The New School for Design, published on the Urban Omnibus website (http://urbanomnibus.net/2013/09/local-connections-the-red-hook-wifi-project/).

122 Red Hook Wi-Fi. About. www.redhookwifi.org. Available at http://redhookwifi.org/about/.

123 Brooklyn Fiber. About Us. www.bkfiber.com. Available at http://bkfiber.com/about.php; Snow, J. (2014, Aug. 15). "When Their Internet Went Down, These Brothers Stood Up." The Wall Street Journal. Available at http://bkfiber.com/press/wsj-bk-fiber.pdf.

124 Wikipedia. Red Hook, Brooklyn. www.wikipedia.org. Available at https://en.wikipedia.org/wiki/Red_Hook,_Brooklyn.

125 New America (2013, Feb. 1). Open Technology Institute. "Case Study: Red Hook Initiative WiFi & Tidepools." Available at https://www.newamerica.org/oti/blog/case-study-red-hook-initiative-wifi-tidepools/.

126 Red Hook Initiative. http://rhicenter.org/.

127 New America. Open Technology Institute. About Us. www.newamerica.org. Available at https://www.newamerica.org/oti/about-us/.

128 Commotion. http://commotionwireless.net/.

129 Case Study: Red Hook Initiative WiFi & Tidepools. Supra n. 125.

The Red Hook WiFi project was launched in 2011. As Tony Schloss, RHI's Director of Media Programs, explained in an interview with Jonathan Baldwin of Urban Omnibus:

> *We decided to create a public WiFi network after conducting a survey, which revealed that many local residents access the Internet primarily through mobile phones—not many people have wireless routers in their houses, and many have one or no computer. When we first set up WiFi around our building, a lot of young people came and sat outside to use it, even when the office was closed, which told us we were providing a needed service.*[130]

That initial installation serving the area surrounding RHI's offices provided an opportunity to begin developing homegrown community-focused applications. Among the first was the "Shout Box," a texting-friendly digital message board allowing anyone to leave a comment and participate in the project. Others included a Bus Time application, the Red Hook WiFi Splash Page, and a Stop & Frisk application (see Figure 13).[131]

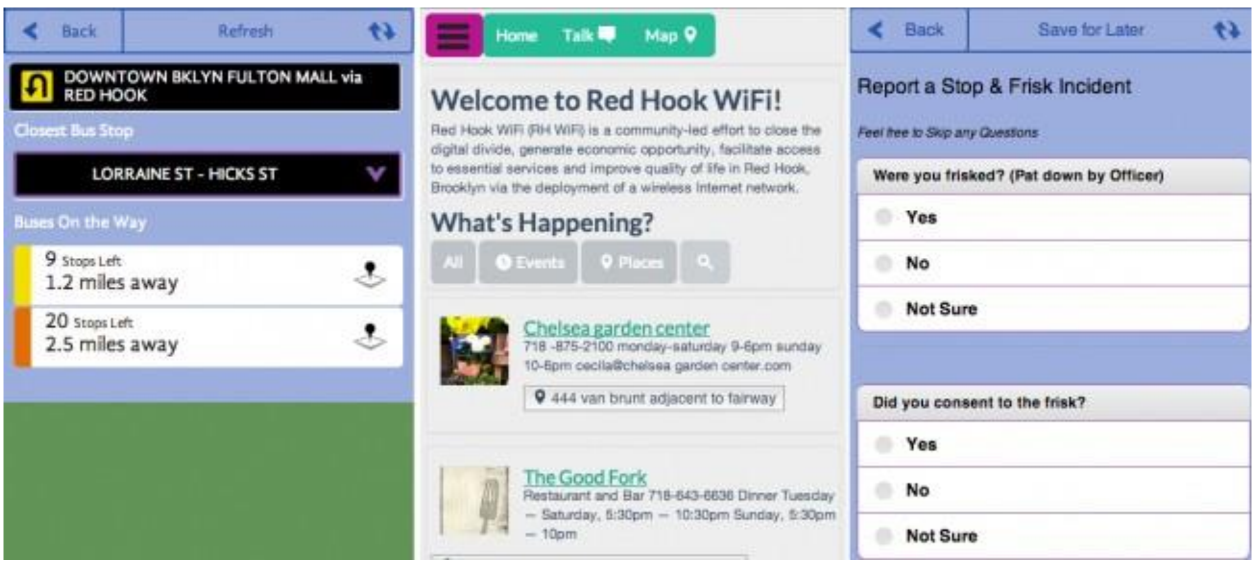

Figure 13: Red Hook WiFi Splash Page

In March of 2012 an additional base station was installed on the roof of an apartment building overlooking a local park and much of the rest of the neighborhood. Later in 2012—roughly a year after its launch—the network was expanded significantly after proving itself as a key communication resource for the Red Hook community during and after Hurricane Sandy. The hurricane hit the area very hard, causing major flooding and taking down cellphone service and other communication infrastructure.

Because the RHI building was one of the few locations that didn't lose power during the hurricane, the Red Hook WiFi network was able to remain active after the storm hit. In

[130] Urban Omnibus (2013, Sep. 25). "Local Connections: The Red Hook WiFi Project." The Architectural League's Urban Omnibus, The Culture of Citymaking. Available at http://urbanomnibus.net/2013/09/local-connections-the-red-hook-wifi-project/.
[131] Ibid.

the days immediately following Sandy's arrival, this led to as many as 300 people per day to use the network to communicate with loved ones, seek assistance and learn what was happening in other areas impacted by the mega-storm.[132] Because text messaging was being widely used by residents after the storm, OTI, in a matter of days, developed an app that enabled residents to text their location and needs to a contact number, which automatically mapped the information and allowed others in the community to respond.

The availability and value of the Wi-Fi network led an Innovation Fellow at the Federal Emergency Management Administration (FEMA) to contact RHI about using the extra routers it had on hand to expand the network to support recovery efforts. The sense of community following the crisis helped make that happen. As Baldwin put it in the interview with Schloss, "before Sandy, we had trouble getting permission to put routers on certain buildings that could serve as crucial nodes in expanding coverage . . . A lot of these frustrating barriers disintegrated after Sandy."

Baldwin's message was echoed by Schloss, who noted that "Sandy really strengthened the ties in the neighborhood." His comments also suggested that, for a community-focused mesh network to grow or even survive, these strong ties may be necessary.

Baldwin also noted the problems RHI faced in getting the network into the area's public housing properties and strategies RHI has used and considered to overcome them:

> *"One obvious thing that's missing is getting the network onto Red Hook Houses property. That was part of the original intent, and we have met with NYCHA to discuss it, but it's a bureaucratic, social, and technical challenge. Because we realized that process would be a long one, we've decided to surround the Red Hook Houses with the network as an interim strategy. We also want to take one building in the Red Hook Houses and see if we can spread the network just through residents putting routers in their apartment windows."*[133]

A key component of the Red Hook WiFi model is to train local residents so they can maintain and expend the network and develop content and services to take advantage of the connectivity it provides. In January 2013, with support from New York City Workforce Development funding, RHI and OTI launched a program to train local young adults aged 19-24 in two key areas: 1) maintaining and expanding the Wi-Fi mesh network and; 2) developing skills in video production and graphic design.[134] The program was modeled on the Digital Stewards curriculum[135] previously developed by OTI and Allied Media Projects (AMP) in support of neighborhood mesh network deployments in Detroit, Michigan,[136] as well as multiple projects overseas.[137]

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[132] Case Study: Red Hook Initiative WiFi & Tidepools. Supra n. 125.
[133] Ibid.
[134] Ibid.
[135] Allied Media Projects. Detroit Community Technology Project. www.alliedmedia.org. Available at https://www.alliedmedia.org/dctp/digitalstewards.
[136] Ibid.
[137] New America (2014, Apr. 18). Open Technology Institute. "Digital Stewardship and Your Community." Available at https://www.newamerica.org/oti/blog/digital-stewardship-and-your-community-2/.

According to an August 22, 2014 article in the New York Times, each Digital Steward "works 20 hours a week (and is paid $8.75 an hour) as part of a yearlong program that teaches skills including mesh networking, video production and web design, culminating in an internship.[138]

The effectiveness of the Red Hook WiFi model as a tool for helping communities deal with hurricanes and other natural disasters has apparently caught the attention of RISE: NYC, a project funded by the New York City Economic Development Corporation (NYCEDC). According to its web site, RISE: NYC "is a Superstorm Sandy business recovery and resiliency program that helps New York City small businesses adapt to and mitigate the impacts of climate change through the use of innovative technologies."[139] Launched in January 2014 with $30 million in grant funding, the program received over 200 applications from over 20 countries around the world.[140]

In April, RISE: NYC announced 11 winners, one of which was New America Foundation's (NAF) Resilient Mesh Wireless initiative,[141] described in a NAF press release as "a collaboration among New America, Sky Packets (one of the country's leading installers of neighborhood Wi-Fi networks), community anchor institutions across the city's five boroughs, and more than five dozen local small businesses."[142] Another winner was Red Hook WiFi.[143]

As described by NAF, its Resilient Mesh Wireless initiative "builds on OTI's experience deploying resilient local networks in the field using Commotion Wireless and other technologies, and particularly its support of the Red Hook WiFi network."[144] This will include "local residents trained as Digital Stewards [who] will design, organize, and build the networks and serve as the primary points of contact for participating businesses."[145]

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138 Cohen, N. (2014, Aug. 22). "Red Hook's Cutting-Edge Wireless Network," The New York Times. Available at http://www.nytimes.com/2014/08/24/nyregion/red-hooks-cutting-edge-wireless-network.html.
139 Rise: NYC. http://rise-nyc.com/.
140 Ibid.
141 New America's Resilient Mesh Wireless Project Wins RISE: NYC Competition. Supra n. 91.
142 Ibid.
143 Rise: NYC. Finalists. Red Hook WiFi. www.rise-nyc.com. Available at http://rise-nyc.com/finalists/red-hook-initiative/.
144 New America's Resilient Mesh Wireless Project Wins RISE: NYC Competition. Supra n. 91.
145 New America. Resilient Communities. Rise: NYC. www.newamerica.org. Available at https://www.newamerica.org/resilient-communities/flexible-future-ready-networks/rise-nyc/.

Example: Botswana UPenn Partnership using TVWS-based telemedicine applications to provide rural residents with access to medical specialists[146]

The Botswana-UPenn Partnership (BUP) pilot project, known as "Project Kgolagano," provides specialist consultations and diagnoses to a patient population that would otherwise have to travel long distances to the capital city of Gaborone, Botswana, in order to receive such care.[147]

The BUP pilot has been supported financially by Microsoft, with the Botswana Innovation Hub (BIH) also contributing some funding.[148] As of August 2016. the project was in the second phase of its evolution. In Phase 1, the project involved two sites connected via TVWS, supported in part by fiber backbone connectivity. After six months, two additional sites were added, along with an expansion of the medical specialties involved.

The project involves two telemedicine applications that use TVWS to support communication between central facilities housing medical specialists with remote clinics where patients are seen by nursing staff.

1. Non-real-time communication with remote specialists supported by high-resolution images captured with smartphone cameras and data entered into electronic health records (EHRs) based on Botswana's national EHR standards.
2. The use of the Skype for Business platform for remote real-time video-enabled discussions of complex cases.

The focus during Phase 1 was on screening, diagnosis and treatment of cervical cancer. In Phase 2, this was expanded to include Dermatology and Complex Medical Conditions, including HIV and Tuberculosis.

The cervical cancer screening application was developed by Vista Life Sciences (VLS),[149] a US-based company that has since opened an office in Botswana. The system employs Nokia-brand smartphones, laptops and 42" LCD monitors equipped with USB/Bluetooth dongles to support device connectivity. Once photos are taken with the smartphone and data is entered into the government-standard electronic health record (HER), these are transmitted to specialists at centralized facilities who receive an

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[146] The following discussion is based largely on an August 23, 2016 phone interview with Kagiso Ndlovu, Health Informatics Program Manager at the Botswana UPenn Partnership.
[147] University of Pennsylvania. Penn Medicine. News Release. "Botswana-UPenn Partnership Teams up with Microsoft and Partners to Launch Telemedicine Service over TV White Spaces Network," March 12, 2015. Available at http://www.uphs.upenn.edu/news/News_Releases/2015/03/botswana/.
[148] The Botswana Innovation Hub (BIH) was incorporated to develop and operate a science and technology park to aid in diversifying the economy and help transform Botswana into a knowledge economy; promote research, development, education and innovation; support start-ups and existing companies; and attract companies, universities, research institutes, and advanced training institutes to join BIH. Go Botwswana. Botswana Investment & Trade Centre. Innovation Hub. www.bitc.co.bw. Available at http://www.bitc.co.bw/innovation-hub.
[149] VistaLifeSciences. Better Information. Better Health. http://www.vistalifesciences.com/.

email notification that this transmission had occurred. The photos are sent as attachments to the EHRs.

Figure 14: Rural Telehealth Application in Botswana[150]

Most participants in the project are medical professionals trained to use the applications. Most of those working at the remote locations are nurses, with doctors located mainly at central facilities (e.g., regional hospitals) linked to these remote locations.

IT support staff is also concentrated at the central facilities and often stretched thin. For example, in Maun, a remote city involved in the project, there were only two or three total IT staff serving a large hospital and more than 10 regional clinics. According to Kagiso Ndlovu, BUP's Health Informatics Program Manager, this small IT staff is not highly trained. As a result, Ndlovu said that, technical problems often require remote consultation or onsite visits to Maun from the staff of a Botswana-based IT consultant and ISP, Global Business Solutions (GBS),[151] which is also involved in the project.

The terrain in the project footprint and Botswana in general is fairly flat, which is helpful in terms of wireless propagation. In some areas, obtaining reliable electricity has been a challenge, which some locations have addressed via generators.

According to Ndlovu, the TVWS technology used in the project is delivering 2 Mbps data rates. This has generally provided enough capacity for the project's current needs, given that the network has relatively few simultaneous users. But Ndlovu also noted that

[150] Figure courtesy of Kagiso Ndlovu, Health Informatics Program Manager at the Botswana UPenn Partnership.
[151] Global Broadband Solution. http://www.gbs.co.bw/about.php.

capacity may become a constraint as more specialties and applications are added in the future.[152]

According to Ndlovu, social and cultural issues did not present significant barriers to adoption. A more significant challenge to adoption was the fact that so many applications and project components were being piloted at the same time.

Based on the project's results, Ndlovu sees TVWS as a potential long-term solution to support telehealth services in remote rural areas, noting that this approach does not require spectrum licenses, and that equipment and installations costs are reasonable, even with early generations of the technology. He compares this cost to using commercial mobile service which, though available in much of Botswana, involves ongoing and often prohibitive usage fees and data caps.

Ndlovu said that the BUP project's longer-term goal is for national government ministries to take over financial responsibility for the project's budget. Toward that end, data collected during the project will be used to support a future cost-benefit analysis, which Ndlovu expects will be undertaken in cooperation with university researchers. He noted that the ratio of patients to doctors in Botswana is very high, especially outside the capitol city. As a result, large and potentially avoidable expenses (e.g., gas, lodging) are incurred when patients must travel to the capitol to gain access to often-overwhelmed specialists and centralized medical facilities.

In addition to potential cost savings, Ndlovu predicted that health outcomes will improve as patients receive more timely screening, diagnosis and treatment, and as remote practitioners gain more access to specialist consultations and training. Given these benefits, he believes there is a "high possibility" that the Botswana government will invest in and adopt TVWS-based telehealth applications, as cost-benefit studies using data from the trial phase more clearly quantify these benefits. Though these studies have yet to be done, Ndlovu noted that an earlier cost-benefit analysis of a mobile telemedicine solution, which was not adopted for other reasons, indicated that large savings could be derived from use of telehealth services provided to remote areas.

Also envisioned, according to Ndlovu, is an expansion of the TVWS network to include schools and educational applications. He indicated that USAID-NetHope[153] may be involved in developing this potential expansion.

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[152] As discussed elsewhere in this report, interviews with TVWS vendors and others indicate that substantially faster data rates will be supported by future generations of TVWS technology.
[153] Net Hope. Our Approach. www.nethope.org. Available at http://nethope.org/our-approach/.

Lessons and Insights

1. Though the early generation TVWS equipment used in the Manhattan Library project provided limited functionality, it: (i) was easy to install; (ii) required minimal ongoing maintenance and; (iii) was heavily utilized, accounting for 37 percent of total library network traffic during colder months and exceeding in-library usage during June-August.
2. The non-line-of-sight functionality and relative ease of installing and relocating TVWS links highlights the potential value of CAI-connected TVWS networks to serve as "second responders" in disasters. Similarly, the Red Hook WiFi mesh network's role in the aftermath of Hurricane Sandy highlights the potential of local mesh networks to support emergency communications, a potential recognized by the award of a RISE: NYC "resilience" grant funded by the New York City Economic Development Corporation.[154]
3. The New Hanover/Wilmington case illustrates the potential value of TVWS to provide low-cost connectivity to support public hotspots as well as a range of other public service and "smart city" applications, including video surveillance in public parks and detention facilities, and remote sensor monitoring. And our Fort Myers case provides a clear and dramatic example of how Millimeter Wave networks can be quickly deployed to support relatively inexpensive and small-footprint, yet very high resolution video surveillance systems in downtown urban areas.
4. Our discussion of the Botswana UPenn Partnership TVWS-based telemedicine project provides an example of the potential benefits from connecting rural health clinics to medical specialists located in urban centers. Though it takes place in Botswana, we believe this project has relevance to rural parts of the U.S., especially tribal areas, which often lack the access to medical expertise enjoyed by urban residents. As this case suggests, wireless telemedicine links using affordable technology capable of supporting the required applications and bandwidths have potential to reduce patient and healthcare system costs, while also improving health outcomes.
5. Interviews with staff from the Manhattan Library and other TVWS pilots, and with TVWS equipment vendors and others familiar with the technology (e.g., Microsoft), strongly suggest that future generations of TVWS equipment will be able to support community hotspot deployments at lower cost and with faster average speeds and improved features compared to those deployed for the Manhattan library project. Similarly, our research indicates that TVWS technology is on the cusp of being economically viable for in-home applications targeting some of the nation's hardest-to-reach unserved areas.

   A specific example of this is the third-generation TVWS system that Carlson Wireless expects to begin shipping in late 2016 or early 2017. As noted above, though final pricing for the system had not been finalized at the time we interviewed Jim Carlson, he indicated that its per-link cost will be roughly an

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[154] New America's Resilient Mesh Wireless Project Wins RISE: NYC Competition. Supra n. 91.

order of magnitude lower than the $2,167 cost for the first generation equipment used in the Manhattan library project, while also supporting a larger number of users and higher throughput per base station. Our interviews with wireless vendors 6Harmonics and Adaptrum indicated that they are also working on significant product enhancements, though neither was prepared to provide details on their next generation products at the time of our interviews.[155]

6. Although it remains unclear exactly how much TVWS will be available after the ongoing incentive auction,[156] interviews with experts and review of published research[157] suggest that sufficient TVWS spectrum will be available in most small towns and rural areas to support community hotspots offering at least reasonably attractive access speeds. TVWS spectrum availability in major metro markets is, however, far more questionable and dependent on the particulars of post-auction FCC decisions.[158]
7. It remains unclear the extent to which the FCC's new E-Rate policy will allow E-Rate funds to support the share of total library network capacity used to provide remote hotspot service or extend in-home access to unserved households (e.g., for so-called "check out hot-spots" based on TVWS technology that could potentially be offered by libraries to patrons lacking at-home broadband access). The FCC recently requested public comment on this question in a Public Notice dated September 19, 2016.[159]

Implications and Considerations for RENs

1. Trials such as the Manhattan GLN pilot and several other projects included in this section suggest that TVWS can provide libraries and other REN-connected CAIs an enhanced ability to extend community connectivity to locations that do not readily support fiber or line-of-sight-dependent wireless connections. This potential may have substantial value in smaller communities—which generally have greater unmet connectivity needs and, as the national map in Figure 8 suggests, are likely to have more available TVWS spectrum than major metro markets.

[155] Aug. 18, 2016 phone interview with Robert Wu, 6Harmonics CEO; Aug. 31, 2016 phone interview with Hanxi Chen, Adaptrum VP of Products and Solutions.
[156] See generally, the 2015 TVWS Report and Order, supra n. 207. Additional information regarding the potential impact of the FCC's incentive auction is available in the accompanying regulatory analysis.
[157] See for instance, Muthukumar, V., Daruna, A., Kamble, V., Harrison, K., & Sahai, A. (2015, June). Whitespaces after the USA's TV incentive auction: A spectrum reallocation case study. In 2015 IEEE International Conference on Communications (ICC) (pp. 7582-7588). IEEE. Available at https://people.eecs.berkeley.edu/~vidya.muthukumar/incentive_auction_whitespaces.pdf.
[158] Federal Communications Commission. FCC Adops Rules For Unlicensed Services in the TV and the 600 MHz Bands. www.fcc.gov. Available at https://www.fcc.gov/document/fcc-adopts-rules-unlicensed-services-tv-and-600-mhz-bands.
[159] 2016 E-Rate Public Notice, supra n. 27.

2. With FCC regulations and spectrum availability subject to change following the ongoing incentive auction, and future equipment expected to offer substantial improvements in cost and performance, RENs may prefer to take a wait and see attitude toward TVWS in the near term. On the other hand, gaining experience with TVWS and its equipment vendors at early stages of product and market volume development could increase RENs' insight and influence as to the evolution of TVWS markets, equipment and regulation.
3. Discussions with GLN, equipment vendors, and others active in the TVWS and "digital inclusion" arenas (e.g., the SHLB Coalition[160]) may help REN leadership evaluate TVWS and other wireless spectrum options. These discussions may also help all parties to better understand options and strategies related to E-Rate support for wireless deployments associated with libraries and schools, as well as other relevant support mechanisms (e.g. Connect America Fund,[161] Lifeline,[162] etc.).
4. Also potentially helpful in evaluating strategic options related to TVWS would be a sufficiently granular understanding of the availability of TVWS in geographic areas served by RENs, and in relation to existing broadband availability and perhaps also to EBS channel availability. Data contributing to such an understanding could potentially be obtained from the FCC and FCC-approved TVWS databases managed by private companies.[163]
5. The range of market areas, applications and frequency bands considered in this section of the report may be useful in broadening the perspective of REN management with regard to potential wireless opportunities in addition to connecting CAIs, students, households and Wi-Fi hotspots.

[160] See Schools, Health & Libraries Broadband Coalition (SHLB). www.shlb.org.
[161] Federal Communications Commission. Connect America Fund (CAF). www.fcc.gov. Available at https://www.fcc.gov/general/connect-america-fund-caf.
[162] Federal Communications Commission. FCC Modernizes Lifeline Program for the Digital Age. www.fcc.gov. Available at https://www.fcc.gov/document/fcc-modernizes-lifeline-program-digital-age.
[163] For example, see data download options for Google Spectrum Database at https://www.google.com/get/spectrumdatabase/data/.

Privately Owned ISPs Using Wireless to Improve Rural and Urban Access

This section of the report includes two case studies, both involving efforts by a locally owned private ISP to improve broadband service in its community. One case focuses on expanding and maintaining service in a very rural environment with challenging topography and climate. The second examines the use of wireless to deliver high-speed connectivity to underserved locations in an urban environment, and providing competitive options for already-served locations in that environment.

The first case focuses on Axiom Technologies, an ISP that uses a number of wireless spectrum bands to reach homes and businesses in rural areas of Maine. Although our case study considers various elements of Axiom's business—which operates largely as a social enterprise focused on supporting its community while being financially sustainable—it also takes a focused look at Axiom's use of TVWS to reach very remote populations and deal with terrain that is especially challenging for line-of-sight-dependent wireless solutions.[164]

The second case examines the use of wireless by Cruzio Internet—in some cases working with the City of Santa Cruz, California—to use E-band millimeter wave (mmW) links to deliver gigabit speeds to office buildings and multiple dwelling units in an urban setting. As our case study explains, Cruzio has found mmW and other wireless technologies to be very complementary to its expansion of fiber connectivity in Santa Cruz. It has also found them to be relatively free of interference from other wireless networks and to be relatively secure and low maintenance, even when compared to the fiber links it has deployed in Santa Cruz.

[164] See Murphy, E.D. (2016, May 25). "Maine County Receives Microsoft Grant to Provide Internet to Rural Homes." Digital Communities. Portland Press Herald (Portland, Maine). Available at http://www.govtech.com/dc/articles/Maine-County-Receives-Microsoft-Grant-to-Provide-Internet-to-Rural-Homes.html.

Case Study: Axiom Technologies, a social enterprise using TVWS to extend broadband access to remote areas of rural Maine[165]

Description

Axiom Technologies is a privately owned wireless Internet service provider operating in Maine, with its offices and primary service area located in Washington County.[166] In key respects, the company operates as a "social enterprise," with a strong focus on expanding broadband availability and digital literacy, especially in hard-to-reach areas with low population density and challenging terrain, weather and economics.

In pursuit of its community-focused goals, Axiom provides broadband Internet services, digital literacy programs and consulting services to municipalities and community anchor institutions, including health centers and libraries. It also provides a range of other IT-related services targeting small and medium-sized businesses, including computer repairs, VOIP services, and web site development. Axiom is also involved in a number of public-service focused broadband initiatives, including the Gigabit Library Network initiative (see Manhattan Public Library case study for more on GLN), and the New England Telehealth Consortium.[167] It also reports good and close working relationships with local governments and CAIs.

Leveraging grants to support rural access and digital literacy

With financial support from twelve State of Maine ConnectME grant awards totaling $1,534,500, Axiom has brought high-speed Internet service to over 100 areas in the state, including 46 towns.[168] Axiom has also used grant support to develop substantial digital literacy training capabilities. This includes a 2010 grant of $1.4 million though the BTOP Sustainable Broadband Adoption program to "provide educational and employment opportunities to sustain and grow three of the largest industries in the county; blueberry farming, fishing and healthcare."[169] Axiom also partnered with the Maine State Library, which received a BTOP Public Computer Center grant to install new computers in 107 libraries across the state, and videoconferencing units in 11 libraries.[170] Axiom's digital literacy classes were offered free of charge in 18 libraries in Washington County, as well as tribal offices, community centers, schools and business locations in the area.[171] And, in collaboration with Sunrise County Economic Council, Axiom received $300,000 in funding from the John T. Gorman Foundation to provide

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[165] This case study is largely informed by the authors' interviews with Susan Corbett, owner and CEO of Axiom (phone interview on Aug. 15, 2016); representatives from Microsoft's Technology Policy Group (phone interview on Aug. 31, 2016); as well as representatives from various TVWS equipment manufacturers and vendors, including Adaptrum (phone interview on Aug. 31, 2016).

[166] More information about Axiom Technologies is available at http://connectwithaxiom.com/.

[167] See New England Telehealth Consortium (NETC) at http://www.netelc.org/.

[168] Axiom Technologies, Overview Document of Axiom Technologies, Education, and Training Center provided by Susan Corbett ("Axiom Overview") at 3. This document was used by Susan Corbett to supplement our interview discussion.

[169] Ibid.

[170] Ibid.

[171] Ibid.

digital literacy classes in Washington County in 2013 and 2014.[172] During the two-year program, over 1,600 students participated in computer skills classes.[173]

Subject to the availability of further funding, Axiom also plans to "connect 65 'Community Learning Centers' with videoconferencing capability, over a 2,568 square mile region, for the purpose of delivering adult and community education," and to provide libraries in Maine with Wi-Fi hotspots for community use and MiFi devices for students lacking home broadband service.[174]

Its digital literacy work eventually led Axiom to establish a non-profit Axiom Education & Training Center (AETC), a 501(c)(3) corporation.[175] Since its establishment in 2014, AETC has trained over 4,000 residents and over 400 businesses and has established itself as a nationally recognized Digital Literacy and Digital Inclusion expert.[176]

A mix of technologies to address a mix of access challenges

To supplement a landline access business that includes DSL resale and fiber to the premise (for businesses), Axiom has relied heavily on fixed wireless to expand its service footprint in a market that is mainly rural and technically and financially challenging. This wireless expansion is based on a multi-frequency strategy that includes both licensed and unlicensed spectrum, with the choice of wireless technology based on the specific local requirements and constraints faced in each area served (e.g., topography, distance, speed and reliability requirements, revenue potential, etc.). This multi-frequency strategy seems common among both rural and urban WISPs.

Axiom uses multiple bands, including:

- Unlicensed: 900 MHz, 2.4 GHz (Wi-Fi), and 5.8 GHz (point-to-point)
- Licensed: 3.6 GHz and 11 GHz
- TV White Spaces

The unlicensed bands (including TV White Spaces) are regulated according to Title 47, Part 15 of the Code of Federal Regulations (C.F.R.)[177] whereas the above licensed

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[172] Ibid.
[173] Ibid.
[174] Ibid at 5.
[175] Ibid at 4. See also Washington County Adult & Community Education and Axiom Education & Training Center at http://www.aetc.us/.
[176] Axiom Overview at 4.
[177] U.S. Government Code of Federal Regulations. Electronic Code of Federal Regulations. www.ecfr.gov. Available at http://www.ecfr.gov/cgi-bin/text-idx?SID=a6d48809cbdf4e208259b1d039efd6d7&mc=true&node=pt47.1.15&rgn=div5.

bands are regulated according to Parts 90 (Section Z)[178] and 101[179] respectively. These regulations are described in detail in the accompanying regulatory analysis.

The initial geographic focus of Axiom's access business was its home region of Washington County, where it is has deployed 90 access points throughout a 2,500 square mile rural region.[180] Of these 90 access points, Axiom is paying rent on only 10, which it considers "a testimony to the support and commitment of the people of Washington County."[181]

According to Axiom CEO Susan Corbett, the company's standard price for basic Internet service is $40/mo., with dedicated connections for businesses and symmetrical service available at higher prices. Current price lists for residential and business service are available at the company's website.[182]

Backhaul for Axiom's access points was originally provided via T1 (copper based) and microwave links, due partly to the high cost of installing fiber. However, this backhaul capacity constraint was largely addressed when BTOP funded Maine's "Three Ring Binder" fiber network, which consisted of 1,100 miles of fiber in 3 rings across Maine, with Washington County included in one of the rings. Thanks to this "Three Ring Binder" project and other developments, backhaul costs have come down significantly. For example, in 2005-2006, when Axiom hoped to replace multiple stacked T1s with a DS3 (digital signal 3) circuit, Verizon's asking price was $30,000 per month. A few years later, Fairpoint (which acquired Verizon's Maine networks and subsequently undertook a major buildout), offered a DS3 for $3,000.

Corbett said that operating expenses are much higher for wireless than for fiber in the challenging rural environment served by Axiom (this contrasts with comments from Cruzio with regard to urban environments in temperate climates, such as Santa Cruz, CA, as discussed later in this report). More specifically, she cites snow and ice, which can prevent maintenance (e.g., climbing tall towers) as well as wind that can turn antennas, challenges that are aggravated by the long distances involved in providing maintenance in rural areas. In terms of power, Corbett stated that Axiom's experiments with solar found it to be an unsuitable source of power in rural Maine, though the company is experimenting with the next generation of solar equipment.

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[178] U.S. Government Code of Federal Regulations. Electronic Code of Federal Regulations. www.ecfr.gov. Available at http://www.ecfr.gov/cgi-bin/text-idx?SID=a7f1867b9888e1d48b4b028603dae4e2&mc=true&node=pt47.5.90&rgn=div5#sp47.5.90.z. See also Federal Communications Commission. 3.5 GHz Band / Citizens Broadband Radio Service. www.fcc.gov. Available at https://www.fcc.gov/rulemaking/12-354.

[179] U.S. Government Code of Federal Regulations. Electronic Code of Federal Regulations. www.ecfr.gov. Available at http://www.ecfr.gov/cgi-bin/text-idx?SID=a7f1867b9888e1d48b4b028603dae4e2&mc=true&node=pt47.5.101&rgn=div5.

[180] Axiom Overview at 5.

[181] Ibid at 3.

[182] Axiom. Residential. www.connectwithaxiom.com. Available at http://www.connectwithaxiom.com/wireless/; Axiom. Business. www.connectwithaxiom.com. Available at http://www.connectwithaxiom.com/business-solutions/.

In light of the intense maintenance challenges it faces, Axiom gives customers credit on their bills for outage time. It also makes in-store equipment available to customers and/or temporarily connects them with a MiFi device from US Cellular. Coupled with proactive conversations with customers, Corbett stated that these customer service policies are important components of Axiom's business model.

Noting that Axiom's mission is to remain financially sustainable while providing valuable public services and good jobs, Corbett noted that salaries are the company's primary expense, followed by tower rents, power, backhaul and general OpEx (insurance, utilities, memberships, office supplies, equipment repairs and replacement).

The value of TVWS for hard to reach areas

Due to its mountainous and heavily forested terrain, serving all of Washington County's approximately 23,000 housing units[183] could not be achieved using only traditional fixed wireless solutions, due largely to line-of-sight limitations. As a consequence, Axiom, with support from a $72,800 grant from Microsoft, has been actively exploring the use of TVWS to reach very remote populations and deal with terrain that is especially challenging for line-of-sight-dependent wireless solutions.[184]

In June 2014, Axiom began deploying Adaptrum's ACRS 2.0 TVWS technology, starting with 5 base sites and 40 customers across the county, with non-line-of-sight distances from the tower to the customer premise ranging from 2 to 5 miles.[185] Later stages of the project were planned to reach 600 customer sites located in densely wooded and hard-to-reach areas.[186]

Its TVWS deployments have required Axiom to deal with and learn from the still-early generations of TVWS technology currently available, as well as the current FCC regulations related to the technology. As part of this learning curve, Axiom, together with Adaptrum, requested and were granted a waiver of the FCC's 100 foot maximum limit for TVWS antenna height.[187] As a result of the waiver, some of Axiom's TVWS

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[183] See U.S. Census Bureau. Quick Facts. Washington County, Maine. www.census.gov. Available at http://www.census.gov/quickfacts/table/HSG010215/23029,00.

[184] See Murphy, E.D. (2016, May 25). "Maine County Receives Microsoft Grant to Provide Internet to Rural Homes." Digital Communities. Portland Press Herald (Portland, Maine). Available at http://www.govtech.com/dc/articles/Maine-County-Receives-Microsoft-Grant-to-Provide-Internet-to-Rural-Homes.html.

[185] Dynamic Spectrum Alliance, Worldwide Commercial Deployments, Pilots, and Trials, at 17. Available at http://dynamicspectrumalliance.org/wp-content/uploads/2016/01/Pilots-and-Trials-Brochure_Jan-16.pdf.

[186] Ibid.

[187] Adaptrum, Inc. (2014). Waiver—Expedited Action Request. Available at https://ecfsapi.fcc.gov/file/60000976684.pdf; Federal Communications Commission (2014). "Office of Engineering and Technology Declares the Adaptrum, Inc. Request for Wavier of Sections 15.709(b)(2) of the Rules to be a 'Permit-but-disclose' Proceeding for Ex Parte Purposes and Requests Comment." Public Notice in ET Docket No. 14-187. Released Oct. 23, 2014. Available at https://ecfsapi.fcc.gov/file/60000975446.pdf. The accompanying regulatory analysis discusses height limits associated with TVWS devices in greater depth.

transmitters are now mounted as high as 250 feet, making them better able to deal with the tall tree lines and other topographical challenges found in parts of its service area.

Figure 15: Example of Maine Topography[188]

Though Axiom's TVWS pilot projects are successfully delivering Internet service to remote households, Corbett noted that current generations of equipment, coupled with FCC power and antenna height restrictions, constrain achievable throughput. Currently, each base station includes up to 10 radios that share 16 megahertz of spectrum via 10 unidirectional antennas that can serve up to 10 subscriber radios. With current equipment and configurations, this is sufficient to satisfy users wanting speeds of 2 Mbps down and 1 Mbps up, which is close to Maine's statewide standard of 3 Mbps down and 1 Mbps up for basic Internet service. But it falls well short of the FCC's current definition of broadband, which requires 25 Mbps download and 3 Mbps upload speeds. Corbett is optimistic, however, that new generations of TVWS equipment

[188] Figure courtesy of Axiom Technologies. Available at http://www.connectwithaxiom.com/about/.

expected by the end of 2016 will allow Axiom to meet the FCC's 25/3 Mbps broadband standard,[189] while increasing the number of customers served per base station.

[189] See Federal Communications Commission. FCC Finds U.S. Broadband Deployment Not Keeping Pace. www.fcc.gov. Available at https://www.fcc.gov/document/fcc-finds-us-broadband-deployment-not-keeping-pace.

Lessons and Insights

1. Private ISPs with strong community ties and sense of public service may, as in the case of Axiom, evaluate economic opportunities and deployment decisions differently than large publicly traded ISPs that are typically focused on much larger market areas and maximizing shareholder rather than local community value.
2. Multi-stakeholder alliances can help develop workable solutions in technically and economically challenging environments (e.g., as noted above, Axiom is affiliated with the Gigabit Library Network initiative and the New England Telehealth Consortium, and has good working relationships with local governments and CAIs). In pursuing such alliances private companies would benefit from having strong local roots and operating, at least to some degree, from a social enterprise-oriented perspective.
3. Cost savings can be achieved by trading free service for antenna access at desirable locations.
4. Digital literacy training is a helpful companion to providing access, by supporting service uptake, building stakeholder support, and enhancing economic and social benefits of access, especially in previously underserved communities.
5. Proactive and locally-anchored customer communications and related policies (e.g., bill credits, public access locations) can be helpful in retaining customer loyalty when dealing with weather-related and other outages, especially in rural areas with challenging weather conditions.
6. Affordable fiber backbone connectivity can improve overall economics. As noted above, in Axiom's case, the BTOP-funded open-access Three Ring Binder project and Fairpoint's upgrade of networks purchased from Verizon, helped reduce backhaul costs by an order of magnitude.
7. Reliable and affordable power can be challenging in remote areas with harsh weather and lack of sunshine which, together, can disqualify solar as a viable option.
8. Speeds and other features provided by current generation of TVWS are limited. However, Corbett and others interviewed for this project anticipate the availability of next generation TVWS equipment in late 2016 and/or 2017, and expect this equipment to support 25/3 Mbps throughput and a larger number of clients per base station, along with smaller CPE footprints and lower costs.

Implications and Considerations for RENs

1. RENs could play a fiber backbone role similar to the Three Ring Binder, working with local and regional WISPs to address gaps in rural connectivity and the backhaul costs associated with doing so.
2. Where suitable local WISP allies are unavailable, RENs could get more involved in providing wireless access, either directly, or by supporting local stakeholders in

developing a WISP organization owned by a local municipality, cooperative or social entrepreneur or via a hybrid model designed specifically for the local situation.

3. With FCC regulations and spectrum availability subject to change following the ongoing incentive auction, and future equipment expected to offer substantial improvements in cost and performance, RENs may want to take a wait and see attitude toward TVWS in the near term. On the other hand, gaining experience with TVWS and its equipment vendors at early stages of product and market volume development could increase RENs' insight and influence as to the evolution of TVWS markets and products.

Case Study: Cruzio Internet and the City of Santa Cruz using Millimeter Wave links to complement fiber and improve connectivity in an urban environment[190]

Description

In this project, Cruzio Internet,[191] a locally-based ISP, worked cooperatively with the City of Santa Cruz and with Siklu,[192] a leading supplier of Millimeter Wave (mmW) wireless links.[193] Siklu provided 1 Gbps E-band (70/80 GHz) mmW equipment at no charge, whereas Cruzio deployed and manages the network. The City's role was limited mainly to identifying target locations, and it did not require Cruzio to provide discounts to affordable housing residents. According to J. Guevara, the city's Economic Development Manager, it was an attractive arrangement for the city to partner with Cruzio, an established local ISP experienced with mmW technology that could support all aspects of service delivery and provide a competitive broadband alternative to potential consumers.[194]

The project involved the installation of Siklu equipment at 17 sites, mostly on rooftops. These sites include key office buildings, public buildings and public housing developments. A minority of the sites were commercial locations. In certain instances, as was the case at City Hall, which already had wireline access, Siklu mmW equipment provides redundancy.

Each affordable housing complex involved in the project shares a 1 Gigabit connection, with service provided at market rates without subsidies. Monthly charges are $10 for

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190 This case study is largely informed by the authors' interviews with J. Guevara, Economic Development Manager for the City of Santa Cruz (phone interview on Aug. 18, 2016); executives at Cruzio Internet (phone interview on Aug. 29, 2016); and Boris Maysel, Director of Business Development at Siklu (phone interview Jul. 26, 2016).

191 The Cruzio website is http://cruzio.com/.

192 The Siklu website is http://www.siklu.com/.

193 Millimeter Wave technology and regulation is discussed in detail in the accompanying regulatory analysis. Additional information is available at Adhikari, P. (2008). Understanding Millimeter Wave Wireless Communication. Loea Corporation. White Paper. Available at http://www.loeacom.com/pdf%20files/L1104-WP_Understanding%20MMWCom.pdf. Additional information about the partnership is available at http://www.siklu.com/santa-cruz-lights-siklus-fiber-like-wireless-gigabit-network-record-time/ and http://www.cityofsantacruz.com/Home/Components/News/News/1923/.

194 Cruzio is an Internet Service Provider (ISP) and Competitive Local Exchange Carrier (CLEC) that serves approximately 9,000 households and businesses in Santa Cruz County. Founded in 1989, Cruzio is one of the largest independent ISPs in California. Residential and commercial offerings include 50 and 100 Mbps service and sometimes 1 Gbps. Speaking with representatives at Cruzio, we learned that Cruzio uses unlicensed frequencies (Wi-Fi) only for point-to-multipoint non-SLA, best efforts services. Devices that exclusively rely on these frequencies are sold for residential or business use as off-the-shelf. Licensed frequencies used by Cruzio are "infrastructure-grade bands" providing "carrier-grade service," with the specific choice of spectrum varying depending upon distance and required capacity. Licensed bands are also used for providing dedicated SLA-type services, mainly to enterprise and institutional customers.

equipment and a $40-50 service fee for a 100 Mbps data-only product. According to Guevara, the network deployment and activation took under three months, highlighting the time-to-market advantage of wireless, with no permitting problems and simple and fast link setup.

Figure 16: Cruzio/Santa Cruz/Siklu mmW Partnership[195]

Prior to the project, residents had two service options, Comcast cable modem service or AT&T U-Verse DSL. Facing increasing competition from Cruzio mmW offerings, the two incumbents have responded, with AT&T submitting permits for a 1 Gigabit product and Comcast launching a faster (200 Mbps) product of its own.

Background

In 2011, the Santa Cruz City Council began exploring ways to establish data infrastructure that would boost the local workforce and community, including attracting technology workers to the city, which is located roughly a half hour's drive from Silicon Valley. Additionally, since 2009, AT&T had faced a number of instances of sabotage to its fiber network, which knocked out Internet and cellphone service throughout Santa Cruz.[196] This underscored the value of broadband redundancy as a component of the city's infrastructure planning.

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[195] Siklu. Santa Cruz Lights Up Siklu's Fiber-Like Wireless Gigabit Network in Record Time. www.siklu.com. Available at http://www.siklu.com/santa-cruz-lights-siklus-fiber-like-wireless-gigabit-network-record-time/.

[196] Gumz, J. (2013, Apr. 16). "Internet, cellphone customers cut off by outage: Fiber cut in Santa Clara County a challenge to repair." Santa Cruz Sentinel. Available at http://www.santacruzsentinel.com/article/ZZ/20130416/NEWS/130417687.

Cruzio, which offers business and resident service in and around Santa Cruz County, had been negotiating with the City of Santa Cruz regarding fiber construction. As discussed further below, Cruzio is experienced with a range of wireline and wireless access technologies, including mmW systems provided by Siklu. Discussions between Cruzio and the City led to an arrangement in which the City decided to partner with Cruzio and Siklu to use mmW to provide a mix of primary and backup links to underserved CAIs, government buildings and affordable housing multiple dwelling units (MDUs).

Serving urban vs. rural areas

Like Axiom, Cruzio uses a mix of technologies, including fiber, DSL resale and multiple wireless frequencies (including both licensed and unlicensed spectrum), with the choice of technology based on specific local requirements (e.g., topography, distance, speed and reliability requirements, and revenue potential).

Not surprisingly, however, the specific technology and marketing strategies that make most sense in urban areas are often quite different from those likely to be most effective in rural areas. Among the key differences between urban and rural areas are housing density and existing broadband availability and competitive dynamics, which together result in very different overall economics and technical requirements.

The Quello Center research team explored some of these differences in an interview with two members of the Cruzio management team, Chris Frost, Director of Technology and Infrastructure, and James Hackett, Director of Business Operations and Development (henceforth referred to as “Cruzio”).

Our interview with Cruzio underscored the reality that, unlike a rural WISP serving previously unserved or underserved residents or businesses (as was often the case for Axiom), an independent urban ISP must deliver relatively high speeds to be competitive with incumbent broadband providers. In Santa Cruz, the latter include Comcast, which offers speeds up to 100-200 Mbps, and AT&T, whose DSL speeds sometimes reach 50 Mbps. As Cruzio pointed out, this precludes some wireless solutions and favors the use of mmW systems, as they are relatively inexpensive, easy to install and can deliver gigabit speeds at the relatively short distances typical of many urban markets.

Though higher speed offerings are necessary to be competitive, Cruzio reports that over the last few years actual average maximum usage among residential customers has remained fairly steady at around 25 Mbps, with streaming applications such as Netflix being the primary drivers of bandwidth usage.

Cruzio also underscored that dealing successfully with the urban MDU market requires proactive strategies for gaining access to individual buildings. Approaches employed by the company on this front include educating and working with building ownership groups and real estate agents, and recruiting “friendly tenants” who can help convince property managers to provide access.

Another key requirement when dealing with MDUs, according to Cruzio, is the need to carefully consider performance- and cost-related factors associated with the condition of each building’s inside wiring, which can vary widely in terms of quality and the cost and methods required to remedy any deficiencies.

Cruzio's experience suggests that its wireless links may actually have lower maintenance costs and less downtime than its fiber links. Given that Axiom Technologies reported the opposite for its network serving remote areas in harsh climate conditions (see Axiom case study), one way to reconcile these two perspectives is to conclude that they reflect two very different realities in terms of the types, frequencies and costs (including travel time) of system failures in these two very different service environments.

Cruzio also pointed out that Santa Cruz is especially well suited for mmW links because buildings are generally well clustered near base station sites and are similar in height and not very tall, making clean line-of-sight connections relatively easy to achieve. Cruzio also cited growth-related benefits of employing small-footprint and easy-to-install wireless technology. For example, when a wireless-served building's penetration and revenue increased sufficiently to justify fiber connectivity, Cruzio will repurpose its wireless link to serve a new building that currently cannot be economically reached with fiber. Over time, this second building's customer base might also grow sufficiently to support a fiber connection, at which point the wireless link would be once again repurposed at another location.

Strengths and weaknesses of mmW wireless

Guevara explained that, although the city viewed mmW as a proven technology that could supplement a fiber infrastructure, it had reservations about using the technology as a backbone network because of line-of-sight issues. Additionally, because weather can impact reliability, the city does not rely on mmW technology for primary links to support emergency services, though it does view it as well suited to provide a valuable source of redundancy for this purpose.

Guevara also noted that mmW technology—and wireless in general—is well suited to support an approach that "cherry picks" customers rather than serving an entire area. This attribute is either a plus or minus depending on one's perspective, with benefits for an operator's internal economics, but with some risks from the perspective of ensuring universal and reasonably equitable broadband availability within a community. Related to this is the challenge of scalability for fixed wireless. As Guevara noted, "eventually a shortage of rooftop space becomes a bottleneck."

Guevara cited Google's recent acquisition of Webpass,[197] a WISP focused on dense urban areas, as an indicator that the Internet giant—which in 2011 launched a fiber-to-the-premise initiative with great fanfare—is coming to realize the potential savings in time and money from using wireless to supplement or even replace the more expensive task of deploying fiber throughout all or most of a city, or even a neighborhood.

In terms of cost, Cruzio reports dramatic reductions in the price of mmW equipment in recent years to roughly $5,000 per link. In contrast, the cost of installing fiber, which

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[197] Bookman, S. (2016, Aug. 9). "Google Fiber's Webpass acquisition may be behind San Jose, other cities' rollout delay." FierceTelecom. Available at http://www.fiercetelecom.com/telecom/google-fiber-s-webpass-acquisition-may-be-behind-san-jose-other-cities-rollout-delay.

tends to be far more labor and time intensive, is not amenable to comparably sharp cost declines.

In terms of security, Cruzio suggests that mmW links (which are encrypted) may actually be more secure than fiber due in part to their narrow beamwidth. One reason for this is that, to intercept an mmW signal, one must generally be at rooftop height and, unlike with lower frequencies (e.g., Wi-Fi), as discussed in the accompanying regulatory analysis, intercepting a mmW signal will generate so much packet loss that it will be relatively easy to detect.

Nevertheless, as underscored by Guevara's comments about using mmW for backup, but not primary links to support emergency services, the technology remains vulnerable to severe signal loss from heavy rain, especially over longer link lengths. Recognizing this risk and eager to ensure reliable high-quality service in a competitive market, Cruzio is conservative regarding the length of its mmW links in relation to vendor specifications, with its longest mmW link being just over one mile.

For links over two miles, 18 GHz is Cruzio's preferred frequency band, in part because FCC regulations allow an 80 megahertz wide channel in this band,[198] which can support 500 Mbps or potentially greater throughput. Though other interviews conducted for this project suggest that this conservative approach to mmW link lengths is fairly typical, a recent presentation by Siklu Director of Business Development Boris Maysel reported that a 15 km link in Los Angeles experienced "only 5 momentary modulation drops during 2 months of operation in [the winter] rainy season," and was operating at its highest capacity for 99 percent of the time during this period.[199] The same presentation cited expected link distances for a 2 Gbps mmW link with 99 percent availability ranging from 10.1 km (6.3 mi) to 17.7 km (11 mi) for major cities around the world, including New York, Hong Kong, London, Melbourne, Seoul, Moscow, Madrid and Denver (in rough ascending order of expected link range).[200]

Siklu also offers an option to integrate a 5 GHz (or other sub-6 GHz band) radio into its mmW gigabit link product, including automatic switching and sharing a single antenna form factor. It claims this multi-band solution will provide a 99.999 percent level of reliability, though at a substantially lower minimum data rate (e.g., 50-200 Mbps) during inclement weather.[201]

[198] See 47 C.F.R. Part 47, §101.147. Available at http://www.ecfr.gov/cgi-bin/text-idx?SID=3e644b9b6304bdd9248940881322f378&mc=true&node=se47.5.101_1147&rgn=div8.
[199] Siklu (2016, Jun.) "Rural Communities Can Get a Gigabit, Too," Slide Presentation at Slide 16. Available at http://www.siklu.com/wp-content/uploads/2016/06/Presentation-Rural-webinar-BBC-June-2016.pdf.
[200] Ibid, Slide 11.
[201] Ibid, Slides 9-10.

Lessons and Insights

1. Dealing successfully with the multiple dwelling unit (MDU) market requires effective and proactive strategies for gaining access to multi-tenant buildings (e.g., educating and working with building ownership groups and real estate agents, and recruiting “friendly tenants” who can help convince property managers to provide access).
2. In the MDU market it is necessary to carefully consider performance- and cost-related factors associated with the state of each building’s inside wiring, which can vary widely in quality and costs to remedy any deficiencies.
3. Urban economics offer more opportunity to justify fiber deployment as part of the connectivity mix, both for local governments and private ISPs.
4. Urban markets are well suited for growth strategies that leverage the “portability” of wireless technology. For example, as penetration and revenue in buildings served by wireless increases, fiber deployment may become economically feasible and desirable to deliver targeted speeds and services, freeing up a wireless link to serve a new building not currently economically reached with fiber.
5. Cruzio’s experience suggests that, at least in urban areas, wireless links may actually have lower maintenance costs and less downtime than fiber links.
6. Similarly, mmW links may prove as or even more secure than fiber, because to intercept a signal one must be at rooftop level and, unlike with lower frequencies (e.g., Wi-Fi), intercepting a mmW signal will generate so much packet loss that it will be easy to detect.
7. Preferred spectrum licenses may not be available in some dense urban areas (e.g., Silicon Valley) but are more likely to be available in smaller cities such as Santa Cruz.

Implications and Considerations for RENs

1. The more urban an area, the higher the probability that competitively priced alternatives to REN backbone connections will be available. Similarly, more urban areas are more likely to face scarcer availability of desirable spectrum licenses, given the increased level of competition and existing network deployments, reflecting their higher concentration of potential customers.
2. The collaboration between the City of Santa Cruz; Cruzio, an independent ISP; and Siklu, a supplier of leading edge wireless communication technology, allowed each to achieve key goals. The City gained expanded high speed access for strategic locations, CAIs and affordable housing units; Cruzio expanded its footprint and customer base; and Siklu gained positive PR and an expanded market presence. Similarly, synergistic multi-stakeholder collaborations may hold promise for RENs considering options for leveraging their fiber networks to

develop new opportunities and revenue streams, including those related to last mile access.

3. In some urban markets and for some locations, mmW links can extend fiber's gigabit-capable speeds to MDUs, institutions, and businesses at much lower costs than would be required to actually extend the fiber itself. An urban hybrid network comprised of fiber and wireless has potential to support high speeds and reliability, as well as flexibility and cost-effectiveness in terms of expanding the network's reach. This raises important questions about what role(s) a REN might play in an arrangement in which a combination of fiber and mmW technology was used to extend last mile connectivity from REN-owned or affiliated fiber points-of-presence.
4. Security concerns may be alleviated rather than aggravated by using mmW technology, though further study of this question is advisable. Similarly, maintenance costs for current-generation urban wireless links may be relatively modest, though further study is advisable here as well.

THEMES EMERGING FROM OUR RESEARCH

EBS and TVWS have potential to help bridge last mile access gaps, though both face limitations, regulatory uncertainties and geographic variability.

Both the Educational Broadband Service (EBS) and Television White Space (TVWS) spectrum bands have significant potential to help bridge the last mile access and “homework” gaps in America’s small towns and rural areas, especially when connected to high-speed fiber backbone networks.

This potential is illustrated in several of our case studies, including: (i) the partnership between Northern Michigan University (NMU) and Merit Network to deploy an EBS based Long Term Evolution (LTE) network in Michigan’s Upper Peninsula; (ii) the Gigabit Library Network (GLN) sponsored TVWS pilot undertaken by the Manhattan Public Library and; (iii) the use of TVWS by private Internet service provider (ISP) Axiom Technologies to serve remote and very hard to reach areas in Maine.

The NMU/Merit case provides a groundbreaking example of a cooperative effort between a technologically progressive university and REN to deploy LTE-based private network service using all five 22.5 megahertz EBS channel blocks to help bridge the homework gap in an underserved, sparsely populated area.[202]

Similarly, the GLN/Manhattan Library and Axiom case studies highlight the potential to use TVWS technology to expand broadband access via hotspots or direct connections to households and businesses in areas not technically or economically serviceable via wireline or line-of-sight-dependent wireless technologies. The GLN/Manhattan library case also raises the prospect of libraries and perhaps other community anchor institutions (CAIs) using TVWS to provide a flexible, low-cost and non-line-of-sight capable backup network for emergency communications.

Part of a solution, but not a silver bullet

These three case studies also highlight the constraints currently facing efforts to use these two spectrum bands to provide last mile access to underserved populations. For example, both spectrum bands face technical challenges. EBS, which uses frequencies in the 2.5 GHz range, is to a large degree dependent on line-of-sight connectivity,[203] whereas TVWS is constrained by Federal Communications Commission (FCC) limits on power and antenna height.[204] Moreover, as an unlicensed band, TVWS is (like Wi-Fi) vulnerable to interference and congestion as usage levels increase (typically in line with population density).

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[202] A discussion of the EBS band plan is available in the accompanying regulatory analysis.
[203] As we note in the regulatory analysis, although EBS does not necessarily require line-of-sight and is considered by the Federal Communications Commission (FCC) to be suitable and available for the provision of mobile telephony/broadband services, it cannot penetrate barriers as well as lower frequencies such as other bands used for mobile service or TVWS.
[204] These limits are discussed in the accompanying regulator analysis.

And though EBS, being exclusively licensed to educational institutions, does not face the same interference and congestion risks faced by unlicensed TVWS, its usage is restricted by its educational purpose.[205] As the accompanying regulatory analysis shows, current EBS licensees are permitted to lease their spectrum to entities (e.g., Sprint) that use it mainly for non-educational usage, a practice that is now fairly widespread. But the FCC waiver granted to NMU does not permit such leasing practices, suggesting that future waivers leading to expanded use of EBS spectrum may impose similar restrictions. The regulatory uncertainty facing EBS leads us to ask (i) whether the NMU/Merit project can and will serve as an attractive and replicable model for waiver-based expansion of EBS spectrum availability and (ii) whether the FCC might eventually make accessible unused EBS spectrum and by what means and on what terms.[206]

Similarly, the availability of TVWS spectrum will remain at least somewhat uncertain until the FCC completes its ongoing incentive auction, the post-auction "repacking" of the broadcast band, and subsequent decisions regarding TVWS availability, including the possibility of ensuring that at least a small number (e.g., three or four) of TVWS channels are available on a nationwide basis.[207] Though our research suggests that this auction-related regulatory uncertainty may have slowed the evolution of high-volume production TVWS chipsets and network products, it also has revealed that this evolution is nevertheless moving forward and is likely to continue doing so, aided in part by enabling regulation and unmet need for broadband connectivity in other countries,

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[205] In particular, a license for an EBS station will be issued only to an accredited institution or to a governmental organization engaged in the formal education of enrolled students or to a nonprofit organization whose purposes are educational and include providing educational and instructional television material to such accredited institutions and governmental organizations. See 47 C.F.R., Part 27 at §27.1201(a) at U.S. Government Code of Federal Regulations. Electronic Code of Federal Regulations. www.ecfr.gov. Available at http://www.ecfr.gov/cgi-bin/text-idx?SID=15e8ef5757f312a02819210847a184e8&mc=true&node=pt47.2.27&rgn=div5.

[206] In 2008, the FCC sought comment on various alternatives for licensing unassigned EBS spectrum, but no action had been taken by the FCC as of the time of writing of this report. Federal Communications Commission (2008). "Amendments of Parts 1, 21, 73, 74 and 101 of the Commission's Rules to Facilitate the Provision of Fixed and Mobile Broadband Access, Educational and Other Advanced Services in the 2150-2162 and 2500-2690 MHz Bands et al." Third Order on Reconsideration and Sixth Memorandum Opinion and Order and Fourth Memorandum Opinion and Order and Second Further Notice of Proposed Rulemaking and Declaratory Ruling in WT Docket No. 03-66, RM-10586 et al. Adopted Mar. 18, 2008. Released Mar. 20, 2008. ("2008 BRS/EBS Order on Recon. et al.") At ¶ 2. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-08-83A1.pdf.

[207] In its 2015 TVWS Report and Order, the FCC granted permission for TVWS devices to operate in the 600 MHz duplex gap (between wireless uplink/downlink bands), guard bands (between TV and wireless downlink bands), and channel 37 subject to certain limitations. Federal Communications Commission (2015). "Amendment of Part 15 of the Commission's Rules for Unlicensed Operations in the Television Bands, Repurposed 600 MHz Band, 600 MHz Guard Bands and Duplex Gap, and Channel 37, et al." Report and Order in ET Docket No. 14-165 and GN Docket No. 12-268. Adopted Aug. 6, 2015. Released Aug. 11, 2015. ("2015 TVWS Report and Order") At ¶ 6. Available at https://www.fcc.gov/document/fcc-adopts-rules-unlicensed-services-tv-and-600-mhz-bands.

particularly those with weak existing telecom infrastructure, low broadband availability, large amounts of unused broadcast spectrum, and relatively large percentages of their population living in rural and often remote areas.[208]

Similarly, while our research suggests that the limited size of the "educational" market has constrained competitive dynamics among vendors seeking to serve it, it also makes clear that several vendors have already stepped up to do so. In addition, the EBS/LTE market will have the benefit of leveraging large global volumes of LTE components and expanding availability and increasing affordability of end-user-devices that support EBS spectrum and dual-SIM operation.

Understanding the "geographic checkerboard" of need and available spectrum options

A key challenge shared by both spectrum bands is that their availability is extremely variable based on geographic location. As several references in the NMU/Merit case study indicate, the pattern of licensing and leasing of EBS spectrum varies greatly across the country. Similarly, as the map provided in the GLN/Manhattan Library case illustrates, the number of available TVWS channels varies greatly by location.

The good news in terms of reaching underserved populations is that the availability of unused and potentially available spectrum in both of these bands tend to be most plentiful outside of major markets, in areas of the country that tend to be relatively poorly served by existing broadband service providers.

In our case studies, we reference sources of data that shed light on the geographic availability of EBS and TVSW spectrum. Further research could also be undertaken to facilitate a more precise understanding of nationwide, statewide or local availability of these bands in relation to existing broadband service availability and at a sufficiently granular level to be useful for policymakers, network planners and other stakeholders.[209]

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[208] For instance, Microsoft has been helping to facilitate a number of international pilots and trials involving TVWS. Microsoft. Dynamic Spectrum and TV White Spaces. www.microsoft.com. Available at https://www.microsoft.com/en-us/research/project/dynamic-spectrum-and-tv-white-spaces/ (see also https://www.microsoft.com/africa/4Afrika/access_pillar/tv-white-spaces.aspx, https://blogs.microsoft.com/firehose/2015/03/13/botswana-innovation-hub-and-microsoft-bring-specialized-medicine-to-remote-areas/#sm.0001c1rjvn1797d6dtd12mq2nyjkn, and http://www.ozy.com/fast-forward/africas-real-silicon-savannah/63069). For a description of other partnerships in relation to TVWS use in Africa, see Johnson, D.L. and Mikeka, C. (2016, Aug. 29). "Malawi and South Africa Pioneer Unused TV Frequencies for Rural Broadband." IEEE Spectrum. Available at http://spectrum.ieee.org/telecom/internet/malawi-and-south-africa-pioneer-unused-tv-frequencies-for-rural-broadband.

[209] For example, data on EBS licensing and existing broadband availability is available via FCC databases, while multiple companies, including Google and Spectrum Bridge, manage TVWS channel availability databases. In addition, private firms have developed fairly detailed cost models that could aid business decisions regarding broadband deployment. For instance, we discussed such modeling with executives at CostQuest Associates, which has expertise in business case and management analysis in telecommunications. For an example of such modeling, see CostQuest Presentation (2006) "Broadband Economics in Rural Wyoming." www.costquest.com. Available at http://www.costquest.com/uploads/pdf/Broadband-Economics-in-Rural-WY-Updated.pdf.

Millimeter waves can provide quickly deployable and inexpensive gigabit links, but are notably vulnerable to rain-induced signal loss.

As illustrated by our case study of Cruzio Internet's strategy as an urban ISP operating in Santa Cruz, CA, millimeter wave (mmW) wireless systems can provide a relatively fast and inexpensive way to expand high speed access to multiple dwelling units (MDUs) and office buildings in urban environments.

With minimal licensing costs ($75 for a non-exclusive 10 year license[210]), relatively low equipment costs, a very small physical footprint, quick and easy installation, and what is sometimes touted as 99 percent reliable data rates in the 1-2 Gbps range, E-band (70/80 GHz) mmW has a lot going for it as a rapid-deployment footprint expansion tool for wireless Internet service providers (WISPs) targeting MDUs and office buildings in urban markets that require data rates competitive with those offered by wireline incumbent cable and telephone companies.

However, these mmW systems can suffer severe signal loss when exposed to heavy rain, which leads some of its users to limit the range of these links to no more than 1-3 miles. As discussed in our Cruzio/Santa Cruz case study, this limitation can be partially overcome (at least when using mmW equipment from Siklu) by integrating a lower-frequency (e.g., 5 GHz) radio into the mmW link. This can upgrade a 99 percent reliable system to a 99.999 percent reliability level, but only at a much-reduced minimum data rate (e.g., 50-200 Mbps) during inclement weather.[211] This approach might be particularly appropriate for locations with more frequent heavy rain than is likely to be found in Santa Cruz, and for applications where this level of performance is acceptable.

For entities with fiber points-of-presence in urban markets and an interest in exploring expansion opportunities in these markets, the Cruzio/Santa Cruz case study sheds light on a potential technology road map for such expansion. As we explain in that case study, MDU-rich urban markets are well suited for growth strategies that leverage the advantages of wireless technology as a tool for rapid and relatively low-cost market entry. For example, as penetration and revenue in buildings served by wireless increases, upgrading to a fiber connection may become economically feasible and desirable. This then frees up the displaced wireless link for rapid deployment at a new building whose ability to financially justify a fiber connection is less clear.

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[210] Siklu (2016, Jun.) "Rural Communities Can Get a Gigabit, Too," Slide Presentation at Slide 17. Available at http://www.siklu.com/wp-content/uploads/2016/06/Presentation-Rural-webinar-BBC-June-2016.pdf. We note that the $75 fee reported by Siklu is at odds with the FCC schedule of charges for application and other filings in wireless telecommunications services. See the accompanying regulatory analysis.

[211] Ibid., Slides 9-10.

To bridge remaining gaps in broadband access and benefits, business models focused on sustainably addressing local needs may be more effective than models that prioritize investor returns.

All of our case studies highlight, to some degree, the importance of and variation in business models and institutional and stakeholder relationships in initiatives aimed at sustainably expanding broadband availability in underserved areas.

One aspect of this is the challenging economics of this task. If the economics to support a sustainably profitable business model to serve them were clear and attractive enough, these areas would already be served by at least one profit-focused private sector provider, and preferably more than one to avoid monopoly market power. Because that is not the case in a number of scenarios that we explore, a network and service model focused on maximizing social value might provide the only available and sustainably evolving solution.

The exploration of such models is evident in all four of our access-focused case studies, albeit in different ways reflecting different situations and different combinations of stakeholders impacted by and seeking to impact these situations. For example, in the NMU/Merit case, we observe a REN (Merit Network) working closely with one of its member organizations (NMU) to leverage the combination of the former's fiber network and related assets and expertise, with the latter's experience providing its students with wireless-connected laptops, managing a private wireless network, and authorization from the FCC to use the full set of EBS spectrum in Michigan's Upper Peninsula. As discussed in this report, their past history of cooperation, compatible mix of assets and expertise, and relationships with other institutions and communities in the target service area are reflected in how Merit and NMU have approached their current collaboration.

The GLN/Manhattan Library TVWS project also reflects a collaboration between non-profit entities, in this case a collection of public libraries seeking to understand how they can use TVWS technology to expand the scope of the Internet connectivity they currently provide to the community within the confines of their library buildings. Whereas GLN is a modestly funded initiative, it has brought together a significant set of public sector stakeholders and TVWS vendors, and catalyzed and archived an informative body of educational material based on real-world pilots that explore a range of strategies for using TVWS to expand broadband access.[212] Another element of collaboration in the Manhattan Library case study is the library staff's discussions with the local city government and county Emergency Management Department about the possibility of using TVWS equipment to provide backup links to support emergency communications in the area. And, more broadly, potential collaboration between library-based TVWS deployments and emergency management entities is an area of focus for the GLN White Space project as a whole.[213]

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[212] See Gigabit Libraries. Libraries White Space Project. www.giglibraries.net. Available at http://giglibraries.net/page-1712342.

[213] See Means, D. (2016, Apr. 14). "SecondNet: Libraries Using TV WhiteSpace to Increase Community Resilience and to Expand Patron Access." Knight News Challenge. Available at https://www.newschallenge.org/challenge/how-might-libraries-serve-21st-century-information-needs/submissions/secondnets-first.

Though Axiom Technologies and Cruzio Internet are both private ISPs, their cases also highlight potential avenues for cooperative models aimed at bridging challenging digital divides. As explained in its case study, Axiom operates largely as a social enterprise that, while striving for financial sustainability, is also very proactive in working with a range of public service-focused entities and funding sources to bridge remaining gaps in broadband access and digital literacy in the state of Maine. And, as we discuss in our Santa Cruz case study, Cruzio worked closely with city officials and mmW vendor Siklu to create a win-win-win strategy for bringing gigabit connectivity to previously underserved government facilities, CAIs and affordable housing communities.

APPENDICES

Appendix 1: The Quilt Network

The Quilt is the national coalition of advanced regional networks for research and education, representing 36 networks across the country. Participants in The Quilt provide advanced network services and applications to over 200 universities and thousands of other educational institutions.[214] As part of its mission, the Quilt aims to influence the national agenda on information technology infrastructure, with particular emphasis on networking for research and education. The Quilt promotes delivery of networking services at lower cost, higher performance and greater reliability and security.

The partner networks providing support for this report are:

Merit Network: Merit Network is a non-profit, Member-owned organization governed by Michigan's public universities. Founded in 1966, Merit owns and operates America's longest-running regional research and education network.[215] Founded by Michigan State University, the University of Michigan, and Wayne State University, Merit pioneered many of the practices and protocols used in today's Internet.[216] Merit's network consists of over 3,800 miles of fiber-optic infrastructure with a backbone that boasts multiple diverse 10Gb paths, connections to Internet and Internet2, and peering agreements with private networks.[217]

MCNC: MCNC is operates a robust, secure, exclusive communications network that has connected institutions of the University of North Carolina System, Duke University, and Wake Forest University to each other, and through advanced research networks such as Internet2 and National Lambda Rail, to the world.[218] Over the last 5 years, MCNC has expanded the reach of its services to non-profit and university hospitals, public safety, libraries and other key CAIs. MCNC's network, NCREN, provides broadband communications technology services that include 17 institutions of the UNC System and General Administration; 95 North Carolina Charter Schools; 27 of the 36 North Carolina Independent Colleges and Universities; 58 North Carolina Community Colleges.

MOREnet: Established in 1991, the Missouri Research and Education Network (MOREnet) provides Internet connectivity, access to Internet2, technical services, resources and support, as well as technical training to Missouri's public sector entities, including K-12 schools, colleges and universities, public libraries, health care, government and other affiliated organizations.[219] As one of the few networks in the country to support 100 gigabit optical paths, MOREnet's shared network allows it to rely

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214 The Quilt. About Us. www.thequilt.net. Available at http://www.thequilt.net/about-us/.
215 Merit. About Us. www.merit.edu. Available at https://www.merit.edu/about-us/.
216 Merit. Merit's History. www.merit.edu. Available at https://www.merit.edu/about-us/merits-history/.
217 Merit. Services. www.merit.edu. Available at https://www.merit.edu/services/.
218 MCNC. About MCNC. www.mcnc.org. Available at https://www.mcnc.org/about.html.
219 MOREnet. About Us. www.more.net. Available at https://www.more.net/content/about-us.

on scale economies to serve the growing bandwidth needs of its more than 700 members across Missouri.[220]

NJEDge: NJEDge is a non-profit technology consortium of academic and research institutions in New Jersey.[221] At the start of 2003, NJEDge.Net had built a state-of-the-art network through a partnership with Verizon. Today there are 53 educational institutions participating in NJEDge.Net, and together they account for a combined total of over one gigabit of Internet and 300 megabits of Internet2 bandwidth traveling over a managed IP infrastructure that covers the entire state.[222] NJEDge.Net introduces emerging technologies and state-of-the-art networking to its partners in academia, government and industry for inter-institutional collaboration, scholarship and research.

NYSERNet: NYSERNet has delivered next-generation Internet services to New York State's research and education community for more than twenty-five years.[223] With a backbone network that extends from Buffalo to New York City with gateways to multiple national research networks and access to the Internet via The Quilt, NYSERNet strives to advance network technology and related applications to satisfy needs common to the institutions comprising New York State's research and education community.

WiscNet: WiscNet is a membership organization that provides research and education networking services to public and private higher education, K12 school districts, libraries, municipalities, and hospitals throughout Wisconsin.[224] Winconsin's WiscNet maintains a high-speed, scalable and robust backbone that provides redundant core routing and hosts caching servers from major commercial partners like Akamai, Google, and Netflix.[225] With over 100 settlement-free peers, WiscNet sees over 100 gigabytes of daily traffic on a network that serves public and private institutions of higher education, K12 school districts, libraries, municipalities, and hospitals throughout Wisconsin.[226]

Appendix 2: The Research Team

This report was written jointly by Mitch Shapiro, Derek Murphy, and Aleks Yankelevich with substantial guidance and help from Bill Dutton as well as support from other experts at Michigan State. Mitch Shapiro is a telecommunications specialist, Derek Murphy is an expert in strategic planning and policy development, and Aleks

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[220] MOREnet. The MOREnet Network. www.more.net. Available at https://www.more.net/content/morenet-network.

[221] NJEDge.Net. About Us. www.njedge.net. Available at http://njedge.net/about-us/.

[222] NJEDge.Net. Background. www.njedge.net. Available at http://njedge.net/about-us/organization-background-history/.

[223] NYSERNet. About NYSERNet. www.nysernet.org. Available at https://www.nysernet.org/about-nysernet/about-us/.

[224] WiscNet. Home. www.wiscnet.net. Available at http://www.wiscnet.net/.

[225] WiscNet. WiscNet Network Services. www.wiscnet.net. Available at http://www.wiscnet.net/network-services/.

[226] WiscNet. WiscNet Members. www.wiscnet.net. Available at http://www.wiscnet.net/members/.

Yankelevich is an industrial organization economist. Bill Dutton, the Director of the Quello Center, is an expert in media and information, as well as Internet studies. The authors have also benefited from support from Professor Bianca Reisdorf, Assistant Director of the Quello Center and a sociologist; Kendall Koning, J.D.; and Professor Tongtong Li, an engineer.

Mitch Shapiro: In addition to working on the present study of wireless strategies for last mile access to broadband networks that is the subject of this and the accompanying regulatory analysis, Mitch Shapiro, a Quello research associate, is engaged with Quello colleagues on research involving digital inequalities in Michigan (with a focus on BTOP programs), supported by a Michigan Applied Public Policy Research grant.

Prior to joining the Quello Center, Mitch has been a consultant with the Berkman Center for Internet and Society at Harvard University, on national broadband access and competitive policy issues, and with broadband mapping projects in Kentucky and Louisiana. He has also worked with Strategic Networks Group and Pulse Broadband; Pike & Fischer, a unit of the Bureau of National Affairs (now Bloomberg BNA); Pangrac & Associates, Probe Reseach and Paul Kagan Associates. Mitch co-founded the IP & Democracy blog and more recently launched the Evolving Human Systems blog, where he has discussed broadband policy and economics, among other things. He received his B.A. in Economics from the University of Michigan and an M.A. in Telecommunications from Michigan State University.

Derek Murphy**:** Derek has over 25 years of experience in strategic planning and policy development, working with community organizations and all levels of government. Derek began his career in 1977 working on international development initiatives, including two years in Botswana. Returning to Canada (Vancouver) in 1982, Derek shifted his focus to community planning and community services, specializing in affordable housing, social planning and economic development. In 1993, Derek moved to southeastern British Columbia, while maintaining his areas of expertise.

Derek has lived and worked in rural British Columbia for the last 21 years, with the last 16 years focused on initiatives promoting economic diversification and innovation, especially through development of telecommunications solutions. Prior to becoming a consultant, Derek was a senior manager in the non-profit sector, developing and delivering a range of social, economic and health programs.

Derek has postgraduate training in economic development and community planning, with a Masters from Carleton University and a BA from McGill University.

Aleks Yankelevich: Aleksandr Yankelevich has been a Research Assistant Professor at the Quello Center since October 2015. During this past academic year, Aleks was invited to be an Adjunct Assistant Professor at the Department of Economics, where he advises and serves as a committee member for multiple students. Prior to joining the Quello center, Aleks worked as an Economist at the FCC Wireless and Wireline Telecommunications Bureaus. At the FCC, he has provided economic expertise on various rule makings, mergers, and secondary market transactions involving the allocation of electromagnetic spectrum for mobile use. In 2013, he received the FCC's Excellence in Economic Analysis Award.

Aleks’s primary research is in the field of industrial organization, where he focuses on firm price discrimination and vertical and horizontal interactions between competitors as well as regulations related to firm strategies and interactions. His current focus is on media and information industries, where he is engaged in research on both wireless and wireline Internet Service Providers, content provision and pricing, and competition between local exchange carriers. Aleks received his Ph.D. in Economics from Washington University in St. Louis in 2011 and Bachelor’s Degrees in Economics and in Management (Summa Cum Laude) from SUNY Binghamton in 2003.

Bill Dutton: William H. Dutton is the Quello Professor of Media and Information Policy at MSU, where he directs the Quello Center. Bill’s research is focused on Internet Studies, focusing on the social and political aspects of the Internet, such as in the development of his conception of ‘The Fifth Estate‘. Prior to arriving at MSU, Bill was the first Professor of Internet Studies at the University of Oxford, where he was the Founding Director of the Oxford Internet Institute (OII), and Fellow of Balliol College. Before coming to Oxford in 2002, he was a Professor in the Annenberg School for Communication at the University of Southern California, where he remains an Emeritus Professor. In the UK, he was a Fulbright Scholar 1986-87, and was National Director of the UK’s Programme on Information and Communication Technologies (PICT) from 1993 to 1996, before returning to Britain to direct the OII.

At MSU, Bill’s Professorship is within the Department of Media and Information. Bill received a Lifetime Achievement Award for his role as Founding Director of the OII. He is also the recipient of the International Communication Association’s (ICA) first Fred Williams’ award for contributions to the study of communication and technology, the William F. Ogburn Lifetime Achievement Award from the Communication and Information Technologies Section of the American Sociological Association in 2014, and was named an ICA Fellow in 2015. Most recently, his article on cultures of the Internet (with Grant Blank) was selected for an Outstanding Author Contribution in the 2016 Emerald Literati Network Awards for Excellence.