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Wireless Innovation for Last Mile Access: A Regulatory Analysis[1]

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EXECUTIVE SUMMARY

Broadband Internet access has become a crucial part of many parts 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 regulatory analysis, as well as the accompanying business strategy and case analysis, we explore an alternative means for broadband expansion: wireless broadband. Although at present, wireless broadband cannot provide anywhere close to the type of 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, as fiber networks might, wireless technology might nevertheless suffice for many modern applications: information acquisition for job search, health, and other needs; distance learning; and even streaming. Second, wireless broadband can permit mobility, something that wireline networks are not designed to provide. 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, our aim is to explore the various regulations and technical aspects that characterize different wireless broadband alternatives, whereas the accompanying report takes a detailed look at implementation of different wireless networks under varying circumstances. Although both analyses are intended to be complementary, they are to a large degree self-contained.

In this report, we first individually explore the historical and policy developments for various spectrum bands that are being actively used or could see near term deployment for the provision of wireless broadband. In addition, for several of these bands, we examine the existing rules governing these bands in the Code of Federal Regulations. In addition to looking at Federal spectrum related regulations, we also consider rules related to wireless infrastructure deployment at both the Federal and State levels. Finally, we synthesize our findings by comparing the costs and benefits associated with different spectrum bands. A number of general findings emerge:

- There are substantial differences in the way that the Federal Communications Commission licenses various spectrum bands, and these differences are not necessarily correlated with wavelength and other technical properties of spectrum. These differences drive both the development of wireless broadband technology and markets.

- Throughput (speed) tends to increase at higher frequencies and the distance over which a wave can propagate decreases, though this relationship is far from perfect and dependent on both technology and regulations.
- Lower frequencies tend to be more suitable for mobility with limits on throughput in most projects that we have explored. In contrast, higher frequencies tend to be used as a substitute for wireline networks when the latter are not economically feasible to deploy. However, technological improvements are rapidly increasing potential speeds at lower frequencies and new regulations are making it possible to achieve mobility at higher frequencies.

Ultimately, we do not envision that wireless broadband will obviate wireline networks in the foreseeable future. However, we are optimistic that wireless broadband will be an important means of narrowing digital divides by both complementing existing wireline deployments and substituting for them when they can suffice to meet existing needs at much lower cost.

Layout of this Report

Section 1 introduces with a brief overview of wireless policy and regulation in the United States. Section 2 provides a detailed overview of radio frequencies that are and can be used in the provision of broadband Internet service with a focus on regulatory and technical specifications and ongoing and new developments. The primary, though not exclusive focus, will be on frequencies that are explored in the accompanying business strategy and case analysis. In particular, these include Educational Broadband Service spectrum, television white spaces, fixed microwave spectrum, and the related millimeter wave spectrum. Section 3 lays out the various Federal Communications Commission and other regulatory policies pertaining to wireless broadband provision, including both Federal and State infrastructure regulation and security compliance. Section 4 overviews the potential pros and cons (including costs and benefits) associated with different spectrum bands and technologies in order to help facilitate an understanding as to which bands or technologies are most suitable in different circumstances. Section 5 concludes with a discussion of ongoing and potential future developments related to wireless broadband.

1. INTRODUCTION

Electromagnetic spectrum—the "airwaves"—is a critical resource for the provision of wireless broadband access to the Internet. Although there are numerous technologies and business strategies that can be relied on to implement wireless broadband, each business plan depends on consistent access to spectrum. In the United States, Congress requires the Federal Communications Commission (FCC) to implement spectrum policies that "promot[e] economic opportunity and competition[,] and ensur[e] that new and innovative technologies are readily accessible to the American people by avoiding excessive concentration of licenses and by disseminating licenses among a wide variety of applicants."[2] Currently, frequency bands between 9 kHz and 275 GHz have been designated for use for radio-communication, which subsumes wireless broadband.[3] This wide range includes frequencies with vastly different propagation characteristics, which are governed by a diverse set of spectrum policies.

This report examines the evolving spectrum policy and regulatory landscape with a focus on the issues, spectrum bands and technologies most relevant or likely to become relevant to potential last-mile extensions of backbone and middle mile fiber networks, particularly those reaching relatively underserved communities. The research approach undertaken here entailed an examination and synthesis of the applicable sections of the Code of Federal Regulations, along with a thorough search of relevant FCC proceedings—including pending proceedings of likely future relevance—updating spectrum rules and policies. This research has been supplemented by interviews with wireless experts and stakeholders, including members of local communities who have sought to extend Internet access by means of wireless spectrum and technology.

1.1. Overview of Wireless Policy and Regulation

In the United States, regulatory responsibility for radio spectrum—which subsumes the portion of the electromagnetic spectrum that is used for wireless communications—is divided between the FCC and the National Telecommunications and Information Administration (NTIA).[4] The FCC was established by the Communications Act of 1934 as an independent U.S. government agency and is directly responsible to Congress.[5] As part of its obligations, the FCC administers spectrum for non-Federal use. This subsumes the state, local government, commercial, and private internal business spectrum that is the subject of this report.

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[2] 47 U.S.C. §309(j)(3)(B). Available at https://www.law.cornell.edu/uscode/text/47/309.
[3] Federal Communications Commission. Radio Spectrum Allocation. www.fcc.gov. Available at https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation.
[4] Federal Communications Commission. Radio Spectrum Allocation. www.fcc.gov. Available at https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation.
[5] Federal Communications Commission. About the FCC. www.fcc.gov. Available at https://www.fcc.gov/consumers/guides/about-fcc.

The FCC applies different licensing and regulatory approaches to different parts of the radio spectrum. For example, spectrum used by mobile wireless service providers is available through initial licensing, primarily by competitive bidding and through resale via secondary market transactions.[6] In the mobile wireless spectrum bands, the FCC takes a flexible use approach whereby licensees determine which services to offer and what technologies to deploy on this spectrum. Since the 1980s, these licenses began to be made available on an exclusive basis over a pre-specified geographic region in blocks generally ranging between 10 megahertz and 30 megahertz in bandwidth.[7] Several of these licenses are also subject to certain stipulations with regard to usage. For example, Educational Broadband Service (EBS) licenses are intended for flexible use to educational institutions or non-profit educational organizations. Excess capacity can be leased to other entities as long as the educational programming requirements are met.[8]

Other radio spectrum that is also capable of Internet broadband service provision is licensed quite differently or not licensed at all. A leading example of this is point-to-point microwave spectrum used to transmit data between cell sites, or between cell sites and network backbones as a cost-effective alternative to traditional copper circuits and fiber optic links. In certain rural and remote locations, microwave is the only practical high-capacity form of backhaul—the means by which sites are connected to each other and to the core network.[9] Microwave spectrum licenses require frequency coordination as well as the filing of an application with the FCC for each microwave link or path containing detailed information concerning the proposed operation.[10]

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[6] Secondary markets for spectrum are markets in which previously issued spectrum is made available for sale by existing license holders. Federal Communications Commission (2015). "Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993. Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services." Eighteenth Report in WT Docket No. 15-125. Adopted Dec. 23, 2015. Released Dec. 23, 2015. ("Eighteenth Mobile Wireless Competition Report") At ¶ 49. Available at https://www.fcc.gov/document/18th-mobile-wireless-competition-report.

[7] Federal Communications Commission (2013). "Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993. Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services." Sixteenth Report in WT Docket No. 11-186. Adopted Mar. 19, 2013. Released Mar. 21, 2003. ("Sixteenth Mobile Wireless Competition Report") At Appendix A. Available at https://www.fcc.gov/document/16th-mobile-competition-report.

[8] 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.

[9] Federal Communications Commission. Unleashing Spectrum for Wireless Backhaul to Promote Broadband Deployment. www.fcc.gov. Available at https://www.fcc.gov/rulemaking/10-153.

[10] Federal Communications Commission (2012). "Amendment of Part 101 of the Commission's Rules to Facilitate the Use of Microwave for Wireless Backhaul and Other uses and to Provide Additional Flexibility to Broadcast Auxiliary Service and Operational Fixed Microwave Licenses, et al." Second Report and Order, Second Further Notice of Proposed Rulemaking, Second Notice of Inquiry, Order on Reconsideration, and Memorandum Opinion and Order in WT Docket No. 10-153 et al. Adopted Aug. 3, 2012. Released Aug. 3, 2012 ("2012 Fixed Microwave

Unlicensed spectrum is spectrum that is open or shared, can be used by anyone, and is often considered as a platform for innovations like Wi-Fi—which refers to wireless Local Area Networks (WLANs) adhering to Institute of Electrical and Electronics Engineers (IEEE) standards.[11] In addition to relying on unlicensed Wi-Fi devices, wireless broadband providers can potentially use devices that take advantage of unused portions of the electromagnetic spectrum—referred to as white spaces. In particular, the FCC has adopted rules to allow unlicensed radio transmitters to operate in the broadcast television spectrum when that spectrum is not used by a licensed service.[12]

In addition to setting policies and rules for particular spectrum bands, the FCC is engaged in the regulation of network infrastructure necessary to provide wireless broadband. In particular, the FCC's Competition & Infrastructure Policy Division develops and implements competition and infrastructure policies to promote the rapid deployment of wireless communications services consistent with environmental and other statutory requirements.[13] For instance, building a new tower or collocating an antenna on an existing structure requires compliance with the FCC's rules for environmental review, which ensure that licensees take appropriate measures to protect environmental and historic resources.[14]

The myriad rules that govern specific licensed and unlicensed spectrum bands are laid out in Title 47 of the Code of Federal Regulations (C.F.R.).[15] The most pertinent rules will be presented below in this report in reference to specific spectrum bands that could be used to facilitate broadband Internet service. Additionally, because technology and

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R&O et al."). Available at https://www.fcc.gov/document/fcc-continues-wireless-backhaul-reform-0.

[11] Federal Communications Commission. FCC Increases 5GHz Spectrum for Wi-Fi, Other Unlicensed Uses. Fact Sheet. www.fcc.gov. Available at https://www.fcc.gov/document/fcc-increases-5ghz-spectrum-wi-fi-other-unlicensed-uses; Wi-Fi Alliance. Wi-Fi Alliance to Ease Setup of home Wi-Fi Networks with New Industry-wide Program. www.wi-fi.org. Available at http://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-to-ease-setup-of-home-wi-fi-networks-with-new-industry-wide.

[12] Federal Communications Commission. White Space Database Administration. www.fcc.gov. Available at https://www.fcc.gov/general/white-space-database-administration; 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, et al. Adopted Aug. 6, 2015. Released Aug. 11, 2015 ("2015 White Spaces Report and Order"). Available at https://www.fcc.gov/document/fcc-adopts-rules-unlicensed-services-tv-and-600-mhz-bands.

[13] Federal Communications Commission. Competition & Infrastructure Policy Division, Wireless Telecommunications Bureau. www.fcc.gov. Available at https://www.fcc.gov/general/competition-infrastructure-policy-division-wireless-telecommunications-bureau.

[14] Federal Communications Commission. Tower and Antenna Siting. www.fcc.gov. Available at https://www.fcc.gov/general/tower-and-antenna-siting.

[15] Federal Communications Commission. Rules & Regulations for Title 47. www.fcc.gov. Available at https://www.fcc.gov/general/rules-regulations-title-47.

competitive dynamics are constantly changing, the FCC regularly updates these rules. The FCC outlines and describes its rulemaking process on its website.[16]

In brief, before the FCC updates its spectrum policies, it issues a notice of proposed rulemaking (NPRM) that provides an opportunity for public comment on the proposal before it can issue a final rule. When an agency issues an NPRM, it is normally published in the Federal Register, accessible at http://www.archives.gov/federal-register/. FCC issued rulemaking documents are available at the FCC's Electronic Document Management System (EDOCS), https://apps.fcc.gov/edocs_public/ and a broader set of documents that includes public comments and ex parte filings is available at the FCC's Electronic Comment Filing System (ECFS), http://apps.fcc.gov/ecfs/.[17]

[16] Federal Communications Commission. Rulemaking process. www.fcc.gov. Available at https://www.fcc.gov/about-fcc/rulemaking-process.

[17] Although these websites are searchable according by proceeding title or description, in the authors' experience, the docket number containing documents relating to a particular proceeding substantially facilitates the process. Docket numbers are contained in many of the notes citing particular FCC proceedings throughout this report.

2. SPECTRUM FOR WIRELESS INTERNET BROADBAND

As the FCC has noted, "access to spectrum is perhaps the most important input for the provision of [] wireless services."[18] Moreover, "because spectrum bands vary in their propagation characteristics, service providers may make use of different bands depending on the nature of the service, geography, density, or other factors in their network build-out."[19] In particular, a wireless signal loses strength at a rate proportional to the square of the distance traveled, limiting signal propagation distance. RF spectrum can be further attenuated due to blockage by objects in the propagation path and is subject to signal loss from reflection, interference from other similar signals sharing the same medium, and potentially interception by third parties.[20]

Because an in-depth analyses of the physical properties of RF spectrum and RF engineering are beyond the scope of this report, going forward, we will take as given the following properties of RF spectrum relied upon throughout the report:

1. Because of their longer wavelengths, lower-frequency signals travel farther than higher-frequency signals.
2. Lower frequency signals are able to better withstand physical barriers such as solid materials and weather phenomena such as rain.
3. Technical factors that impact the distance that an RF frequency (signal) can travel include transmission power, receiver quality, antenna characteristics, and interference.

A recent non-technical treatment of these properties can be found in Annabel Dodd's "The Essential Guide to Telecommunications," a more complete intermediate treatment is available in John Richards's "Radio Wave Propagation: An Introduction for the Non-Specialist," and a more advanced treatment that requires some engineering background is available in John Seybold's "Introduction to RF Propagation."[21]

In the remainder of this section, we provide an overview of various spectrum bands that could be used to offer wireless broadband under different circumstances with a focus on regulation and technical characteristics. We focus on frequency bands used by various entities and localities represented by individuals whom the authors interviewed as part of their case level analyses used in the accompanying business strategy and case analysis. The different categories of spectrum are grouped according to use, which is driven by a combination of regulatory and technical characteristics.

2.1. Educational Broadband Service

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[18] Sixteenth Mobile Wireless Competition Report at 17.
[19] Ibid.
[20] Dowla, F. (2003). *Handbook of RF and wireless technologies*. Newnes, Burlington, MA.
[21] Dodd, A.Z. (2012). *The Essential Guide to Telecommunications*. Prentice Hall, Upper Saddle River, NJ; Richards, J. A. (2008). *Radio Wave Propagation: An introduction for the non-specialist*. Springer Science & Business Media, Berlin; Seybold, J. S. (2005). *Introduction to RF propagation*. John Wiley & Sons, Hoboken, NJ

The Educational Broadband Service (EBS), formerly known as the Instructional Television Fixed Service (ITFS), is an educational service that has generally been used for the transmission of instructional material to accredited educational institutions and non-educational institutions such as hospitals and training centers.[22] Together with the Broadband Radio Service (BRS), this spectrum comprises the 2496-2690 MHz (2.5 GHz) band. BRS is discussed briefly together with other spectrum bands generally used by mobile wireless service providers in Section 2.5.

The FCC views EBS as one of the frequency bands that is suitable and available for the provision of mobile telephony/broadband services.[23] For bands that the FCC considers suitable and available for mobile service, the agency undertakes a competitive review of secondary market transactions to prevent undue concentration of spectrum. Particular attention is paid when a competitor holds in excess of the FCC's spectrum screen, which gauges whether the competitor would hold more than roughly one-third of all suitable and available spectrum in a particular market after the transaction.[24] As of mid-June 2014, the FCC added 89 of the total 112.5 megahertz of EBS spectrum to its spectrum screen.[25] Although EBS is toward the higher end of frequencies currently used to provide mobile wireless service, the frequency is nevertheless substantially lower than several other frequencies discussed in this report with propagation characteristics that make it appropriate for mobile wireless communication. In particular, although EBS spectrum cannot penetrate barriers the way that lower frequencies can, it does not necessarily require line-of-sight between the device and the base station, hence its suitability for mobile broadband.

History:

The FCC established the current 2.5 GHz band plan in 2004, with a process for licensees to transition from the existing band configuration to the new band plan.[26] In 1963, the FCC established the Instructional Television Fixed Service (ITFS) in the 2.5 GHz band, envisioning that it would be used for transmission of instructional material to accredited public and private schools, colleges, and universities for the formal education of students.[27] Other uses included the transmission of cultural and entertainment

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[22] 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.

[23] In particular, suitability is based upon whether the spectrum band at issue is capable of supporting mobile service given its physical properties and the state of equipment technology, whether the spectrum is licensed with a mobile allocation and corresponding service rules, and whether the spectrum is committed to another use that effectively precludes its uses for the relevant mobile services. Sixteenth Mobile Wireless Competition Report at ¶ 54.

[24] Federal Communications Commission (2014). "Fact Sheet: FCC Mobile Spectrum Holdings Rules." Released May 15, 2014. Available at https://apps.fcc.gov/edocs_public/attachmatch/DOC-327110A1.pdf.

[25] Federal Communications Commission (2014). "Policies Regarding Mobile Spectrum Holdings et al." Report and Order in WT Docket No. 12-269 et al. Adopted May 15, 2014. Released Jun. 2, 2014. ("2014 Mobile Spectrum Holdings Report and Order") At ¶¶ 7-8, 107-125. Available at https://www.fcc.gov/document/mobile-spectrum-holdings-report-and-order.

[26] 2014 Mobile Spectrum Holdings Report and Order at ¶ 107.

[27] Federal Communications Commission (2004). "Amendments of Parts 1, 21, 73, 74 and 101 of the Commission's Rules to Facilitate the Provision of Fixed and Mobile Broadband Access,

material to educational institutions, transmission of instructional material to non-educational institutions such as hospitals, nursing homes, training centers, clinics, rehabilitation centers, commercial and industrial establishments, and professional groups, and performance of related services directly concerned with formal or informal instruction and training.[28]

In 1983, the FCC determined that the ITFS spectrum was underutilized given that there were a substantial number of unused ITFS channels in many areas of the country, with several states having no ITFS licensees whatsoever, and re-allocated several channels for wireless cable (at that time, the Multipoint Distribution Service—MDS—in the 2.5 GHz band).[29] At that time, and further in 1985, the FCC relaxed restrictions governing the leasing of excess capacity to commercial providers, so that as of 1985, ITFS operators could lease up to 95 percent of their capacity for non-educational purposes.[30]

In 2002, the Wireless Communications Association (WCA), National Instructional Television Fixed Service (NIA) and Catholic Television Network (CTN) (collectively, the Coalition) recommended fundamental changes to the rules governing the 2.5 GHz band, arguing that the band was not being used to the fullest extent possible and envisioning that the band could be used to provide wireless two-way broadband services based on a low-power cellular concept.[31]

At the time that the FCC was considering the Coalition proposal, and since 1995, the Commission had not accepted new applications for ITFS licenses, nor auctioned new ITFS spectrum.[32] Because it sought to undertake a comprehensive review of ITFS services, including seeking comment on virtually every area related to the services, the FCC in 2003 determined that it would be appropriate to suspend the acceptance and processing of applications at that time.[33]

In 2004, taking into consideration various aspects of the Coalition's proposal, the FCC adopted a plan to restructure the 2.5 GHz band into upper and lower-band segments for low-power operations, and a mid-band segment for high-power operations. The ITFS service was renamed as EBS (similarly, MDS services in the band were renamed to BRS), which would henceforth be licensed on a geographic area basis according to

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Educational and Other Advanced Services in the 2150-2162 and 2500-2690 MHz Bands et al." Report and Order and Further Notice of Proposed Rulemaking in WT Docket No. 03-66, RM-10586, et al. Adopted Jun. 10, 2004. Released Jul. 29, 2004. ("2004 BRS/EBS Report and Order") At ¶ 10. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-04-135A1.pdf.

[28] Ibid.

[29] Ibid. at ¶¶ 11-12.

[30] Ibid. at ¶ 12.

[31] Ibid. at ¶ 16.

[32] Federal Communications Commission (2003). "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." Notice of Proposed Rule Making and Memorandum Opinion and Order in WT Docket No. 03-66, RM-10586, et al. Adopted Mar. 13, 2003. Released Apr. 2, 2003. ("2003 BRS/EBS NPRM and MO&O.") At ¶¶ 21-22.

[33] Ibid. at ¶ 229.

flexible licenses that permitted licensees to employ the technologies of their choice.[34] Among other technical rules, signal strength limits for the low-power bands at the boundaries of the geographic service areas were set at 47 dBμV/m and transmitter output power of response stations was restricted to 2.0 watts.[35]

The FCC further modified rules governing EBS in subsequent Orders. In 2006, the FCC permitted EBS licensees to enter into a lease with a maximum term of thirty years, subject to conditions designed to ensure that EBS licensees have a fair opportunity to re-evaluate their educational needs. [36] At the same time, it deferred accepting applications for any remaining unused EBS spectrum until the completion of incumbent-organized transitions to the new band plan.[37] In 2014, recognizing Sprint's control (including through EBS lease arrangements) of Clearwire holdings of approximately 120 megahertz of 2.5 GHz spectrum in 90 of the top 100 U.S. markets and Sprint's intent to use the service for Long-Term Evolution (LTE) wireless communication, the FCC determined that the majority of the EBS band was suitable and available for mobile telephony/mobile broadband services, thereby including 89 of the total 112.5 megahertz of EBS spectrum in its spectrum screen.[38] However, since 1995, no educational entity had been able to apply for a license for EBS in areas where the Commission had not previously assigned a license (so called EBS "white spaces") and likewise, no commercial wireless provider has had the opportunity to lease EBS spectrum in these areas.[39]

In 2008, in seeking comment on various alternatives for licensing unassigned EBS spectrum, the FCC asked whether it would be in the public interest to develop a scheme for licensing unassigned EBS spectrum that avoids mutual exclusivity—a situation in which multiple applicants desire the same EBS license—and whether EBS eligible entities could participate fully in a spectrum auction.[40] In 2014, CTN, the National EBS

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[34] Ibid. at ¶ 6. Geographic area licensing would replace licensing according to individual transmitters. As part of a Further Notice of Proposed Rulemaking released together with the Report and Order, the FCC proposed to assign any new licenses for spectrum in the 2.5 GHz band by auction on a Major Economic Area and Economic Area geographic basis, depending on the particular band segment. Ibid. at ¶¶ 266, 274.

[35] Ibid.

[36] Federal Communications Commission (2006). "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." Order on Reconsideration and Fifth Memorandum Opinion and Order and Third Memorandum Opinion and Order and Second Report and Order in WT Docket No. 03-66, RM-10586 et al. Adopted Apr. 12, 2006. Released Apr. 27, 2006. ("2006 BRS/EBS Order on Recon. et al.") At ¶ 4. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-06-46A1.pdf.

[37] Ibid at ¶ 5.

[38] 2014 Mobile Spectrum Holdings Report and Order at ¶¶ 118-119.

[39] 2014 Mobile Spectrum Holdings Report and Order at ¶ 124.

[40] 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

Association (NEBSA), the Wireless Communications Association International (WCAI), and the Hispanic Information and Telecommunications Network, Inc. (HITN) submitted a "consensus proposal" to license remaining EBS that would avoid competitive bidding, however, to our knowledge, no further FCC action had been taken at the time of writing of this report.[41]

Licensing, Leasing, and Technical Standards:

The service rules for BRS and EBS are set out in 47 C.F.R., Part 27.[42] An overview of the most pertinent rules specific to the EBS band follows:

Subject to technical and other rules described in 47 C.F.R., Part 27 (Subpart M) and certain technical and other rules described in 47 C.F.R., Part 27 (Subpart A), EBS licensees may provide any services for which its frequency bands are allocated as set forth in the non-Federal Government column of the Table of Allocations in §2.106.[43] The table, which is regularly updated and available at the FCC Website,[44] stipulates that licensees may use the 2.5 GHz band for fixed and mobile wireless service with the exception of aeronautical mobile service.

Licensing (Subpart M): A license for an Educational Broadband Service 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.[45] EBS licenses shall be issued for a period of 10 years beginning with the date of grant.[46]

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.

[41] The Catholic Technology Network, the National EBS Association, the Wireless Communications Association International, and the Hispanic Information and Telecommunications Network, Inc. (2014). "Consensus Proposal; EBS Licensing – WT Docket No 03-066." Ex Parte Communication in WT Docket No. 03-66. Received Jul. 18, 2014. Posted Jul. 21, 2014. ("2014 Consensus Proposal") Available at https://ecfsapi.fcc.gov/file/7521245411.pdf.

[42] 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; 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=4536075de7751b9a46fb4510fb848bbd&mc=true&node=pt47.2.27&rgn=div5#se47.2.27_11.

[43] Federal Communications Commission, Office of Engineering and Technology (2016). "FCC Online Table of Frequency Allocations." 47 C.F.R. §2.106. Revised on Aug. 31, 2016. Available at https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf.

[44] Federal Communications Commission. Radio Spectrum Allocation. www.fcc.gov. Available at https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation.

[45] §27.1201(a).

[46] §27.1212(a).

Those applicant organizations whose eligibility is established by service to accredited institutional or governmental organizations must submit documentation from proposed receive sites demonstrating that they will receive and use the applicant's educational usage.[47] Where educational or instructional video services are proposed, the letter should discuss the types of programming and hours per week of formal and informal programming expected to be used and the site's involvement in the planning, scheduling and production of programming.[48]

Educational Broadband Service stations are intended primarily through the use of video, data, or voice transmissions to further the educational mission of accredited public and private schools, colleges and universities providing a formal educational and cultural development to enrolled students.[49] However, BRS and EBS licensees are authorized to provide fixed or mobile service subject to the previous and related stipulations and certain technical requirements.[50]

The Geographic Service Area (GSA) for EBS licensees is the area for incumbent site-based licensees that is bounded by a circle having a 35 mile radius and centered at the station's reference coordinates, which was the previous Protected Service Area (PSA) entitled to incumbent licensees prior to January 10, 2005, and is bounded by the chord(s) drawn between intersection points of the licensee's previous 35 mile PSA and those of respective adjacent market, co-channel licensees.[51] In other words, where two GSA stations have overlapping PSAs, the GSA of each license may be reduced due to the "splitting the football" approach used to divide the overlap area between the licensees.[52]

Leasing (Subpart M): A licensee in the EBS that is solely utilizing analog transmissions may enter into a spectrum leasing arrangement to transmit material other than the educational programming defined in §27.1203. Before entering into a spectrum leasing arrangement involving material other than educational programming on any one channel, the licensee must provide at least 20 hours per week of EBS educational programming on that channel (with certain exceptions) and an additional 20 hours per week per channel must be strictly reserved for EBS use and not used for non-EBS purposes, or reserved for recapture by the EBS licensee for its EBS educational usage.[53] The licensee may shift its requisite EBS educational usage onto fewer than its authorized number of channels, via channel mapping or channel loading technology, so that it can enter into a spectrum leasing arrangement involving full-time channel capacity on its EBS station and/or associated EBS booster stations, subject to the

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[47] §27.1201(a)(3).
[48] Ibid.
[49] §27.1203(c).
[50] §27.1203(a).
[51] §27.1206(a)(1).
[52] Federal Communications Commission. BRS & EBS Radio Services. Licensing. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=licensing&id=ebs_brs.
[53] §27.1214(a)(1).

condition that it provide a total average of at least 20 hours per channel per week of EBS educational usage on its authorized channels.[54]

A licensee utilizing digital transmissions on any of its licensed channels may enter into a spectrum leasing arrangement to transmit material other than the educational programming defined in §27.1203.[55] In order to do so, the licensee must reserve a minimum of 5% of the capacity of its channels for educational uses.[56] In addition, before leasing excess capacity, the licensee must provide at least 20 hours per licensed channel per week of EBS educational usage (subject to certain stipulations).[57] This 5% reservation and this 20 hours per licensed channel per week EBS educational usage requirement shall apply spectrally over the licensee's whole actual service area.[58] As with analog transmission, the licensee may shift its requisite EBS educational usage onto fewer than its authorized number of channels, via channel mapping or channel loading technology and may shift its requisite EBS educational usage onto channels not authorized to it, subject to the condition that it provide a total average of at least 20 hours per licensed channel per week of EBS educational usage.[59]

Construction Requirements (Subpart B): EBS licensees originally issued an EBS license prior to November 6, 2009 had to make a showing of substantial service no later than May 1, 2011, with licensees that had not met service requirements by that time having to do so on a case by case basis.[60] The rules for showing substantial service, which are laid out in §27.14(o), are quite lengthy and specific to among other things, the population density of the location to which the license applies.

Technical Standards (Subparts C and M): An illustration of the BRS and EBS band plan is available on the FCC Website[61] and technical standards are laid out in §27.50(h), §27.53(m), §27.55(a)(4), §27.58, and §27.1220 as well as other sections of 47 C.F.R., Part 27 (Subpart C) that are applicable to all bands subject to Part 27 (e.g., §27.51 discussing equipment authorization and §27.52 discussing RF safety). In particular, Section 27.50(h) broadly lays out power limits that apply to BRS and EBS and Section 27.53(m) lays out emission limits for these bands. Section 27.55(a)(4) lays out power strength limits. Finally, Section 27.58 sets out rules regarding potential interference to BRS and EBS receivers by Wireless Communication Services (WCS) licensees whereas Section 27.1220 lays out rules for height benchmarking for pairs of base station and signal power levels used to resolve issues of interference between proximate base stations. It is worth emphasizing that in contrast to many of the licensed point-to-point frequencies discussed in this report, EBS is presently capable of being used for mobile wireless and fixed point-to-multipoint service and licenses are granted

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[54] §27.1214(a)(3).
[55] §27.1214(b).
[56] §27.1214(b)(1).
[57] Ibid.
[58] Ibid.
[59] §27.1214(b)(2).
[60] §27.14(o).
[61] Federal Communications Commission. BRS & EBS Radio Services. Data. Band Plan. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=service_bandplan&id=ebs_brs.

on a geographic service area basis—so that the licensee or lessee holding on to a particular block of spectrum can expect that other entities will not utilize spectrum in that block over the relevant GSA.

Discussion:

As part of our research on EBS, we interviewed various individuals representing two educational institutions presently relying and seeking to further utilize EBS spectrum to expand Internet broadband access for education and for underserved communities more broadly. The discussions and findings from these interviews are considered in more detail in the accompanying business strategy and case analysis; whereas here, we focus on the licensing aspects related to EBS service provision.

We interviewed representatives from Merit Network and Northern Michigan University (NMU), which have partnered to provide service in parts of the Michigan Upper Peninsula as well as with the Chief Information Officer at Albemarle County Public Schools (Albemarle), a school district serving Albemarle County, Virginia. As mentioned previously, at the time of the adoption of the Mobile Spectrum Holdings Report and Order, no new EBS license had been issued since 1995, meaning that from a geographic perspective, EBS white space remained throughout the United States, with availability depending on the particular block of EBS. Thus, different entities wishing to employ EBS to offer service could potentially take very different routes to obtain an EBS license depending on whether or not they served areas in which previous EBS licenses had been issued.

According to CIO Vincent Scheivert (phone interview on Aug. 15, 2016), Albemarle County Public Schools presently holds a license for the 22.5 megahertz EBS B Block throughout Albemarle County, which has a land area of 726 sq mi. The license was initially issued to Albemarle County Public Schools and has not been transferred. We note that because an EBS GSA has a 35 mile radius, at an area of approximately 3,848 sq mi, the license can more than encompass the entire county. By searching the FCC's Universal Licensing System (ULS), we confirmed that the City School Board of Albemarle County holds EBS license WLX519, which based on 2010 U.S. Census data, covers a population of approximately 393,000. Additionally, from our conversation with Mr. Scheivert and our search of the FCC's Universal Licensing System, we learned that other entities hold EBS licenses that overlap the EBS B Block, such that Albemarle could potentially obtain additional EBS spectrum on the secondary market should it wish to enhance the quality of its service.[62]

In contrast, from our discussion with Dave Maki, CIO of NMU (in-person interview on Aug. 3, 2016), we learned that EBS had not been licensed in the areas of Michigan where NMU sought to provide service. In order to circumvent the hurdles posed by the FCC's 2003 filing freeze, which remained in effect at the time of writing of this report, NMU filed waivers with the FCC in November 2015, requesting the use of all 112.5

[62] For example, Charlottesville Public Schools holds overlapping 22.5 megahertz EBS A Block license WLX523, which is presently leased to Utopian Wireless Corporation through May 16, 2022. George Mason University Instructional Foundation Inc. holds the overlapping 22.5 megahertz EBS C Block license WLX728, which is presently leased to Fixed Wireless Holdings, LLC, a subsidiary of Sprint, through Oct. 28, 2022.

megahertz of EBS spectrum, consisting of blocks A-D and block G.[63] The filings required NMU to provide detailed plans for use of the EBS licenses in accordance with the FCC's requirements for EBS (as articulated above), including detailed plans for network construction and operation.[64] The waivers were granted in April 2016.[65]

For entities wishing to gain access to an EBS license the authors speculate that there are various commercial services that can identify existing EBS spectrum available for transfer or lease on the secondary market or EBS white spaces where the FCC had not previously granted a license. However, in the case of previously issued licenses, because all EBS license applicants must file with the FCC, an entity seeking a transfer or lease on the secondary market may alternatively query the FCC's Universal License System, which contains an up to date record of these licenses. ULS can be accessed at http://wireless.fcc.gov/uls, and is searchable according to license or application. In particular, for readers wishing to gain a broad overview of all EBS licenses (including lease information) for a particular state, ULS offers an advanced search feature where all EBS licenses can be located by designating the particular state and the EBS radio service code, ED.[66]

2.2. Television White Spaces

FCC rules provide for operation of low power unlicensed wireless devices in the broadcast television spectrum (TV bands) at locations where that spectrum is unused by licensed services.[67] These rules also contain provisions for devices that rely on spectrum sensing to determine available channels.[68] This unused TV spectrum is commonly referred to as television "white spaces" (TVWS).[69]

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[63] Northern Michigan University (FRN: 0002735751). FCC Form 601: Applications for Educational Broadband Service Licenses: Northeastern Wisconsin Tribal Service Area, Western Upper Peninsula Service Area, Central Upper Peninsula Service Area, Southern Upper Peninsula Service Area, East Central Upper Peninsula Service Area, Eastern Upper Peninsula Service Area. Exhibit B: Waiver Request. Filed Nov. 13, 2015. Granted Apr. 05, 2016. Available at http://wireless2.fcc.gov/UlsApp/ApplicationSearch/applMain.jsp?applID=9574309.

[64] These waivers included a discussion on NMU's previous success in the construction and operation of an EBS-based WiMAX network since 2007. As discussed in the accompanying business strategy report, NMU plans to use these licenses to construct an LTE network to support the needs of students and the communities in which they live.

[65] 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. Available at http://wireless2.fcc.gov/UlsApp/ApplicationSearch/applMain.jsp?applID=9574309.

[66] See http://wireless2.fcc.gov/UlsApp/UlsSearch/searchAdvanced.jsp.

[67] Federal Communications Commission. White Space Database Administrators Guide. www.fcc.gov. Available at https://www.fcc.gov/general/white-space-database-administrators-guide.

[68] Ibid.

[69] Ibid.

The fixed devices that are being deployed today are typically used to provide backhaul services for Internet connectivity offered by wireless Internet service providers (WISPs), schools and libraries.[70] Some deployments use white space technology for transmission to remote areas where the signals are converted to Wi-Fi signals for direct access by users, although this may not need to be the case in the future.[71] Indeed, the propagation range of the TV bands, which consists of spectrum frequencies below 1 GHz, is well suited to providing broadband connectivity to un-served or under-served areas of the country at relatively low cost.[72]

As part of its efforts to meet demand for video and broadband services, upon authorization by Congress in 2012, the FCC implemented what it termed the "Incentive Auction" to repurpose up to 126 megahertz of TV band spectrum, primarily in the 600 MHz band.[73] Unlicensed white space devices and wireless microphones will continue to operate on vacant channels in the TV bands following the auction, albeit they may be fewer in number in certain geographic areas.[74] The devices will also be permitted to operate on segments of the 600 MHz spectrum that will be recovered and repurposed for new wireless services.[75] However, there remains a degree of uncertainty involving the amount of TVWS spectrum to be available once the auction concludes. At the time that this report was finalized, three rounds of the reverse auction used to determine the price at which broadcasters would voluntarily relinquish their spectrum had concluded and three rounds of the forward auction used to determine prices companies are willing to pay for flexible use wireless licenses had failed to raise sufficient revenue for the reverse auction.[76]

History:

In 2008, the FCC adopted rules to allow unlicensed radio transmitters to operate in the broadcast television spectrum at locations where that spectrum was not being used by

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[70] 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.

[71] Ibid. at ¶ 1, n. 2.

[72] Ibid. at ¶ 1. The frequency bands allocated for television broadcasting are 54-72 MHz (channels 2-4), 76-88 MHz (channels 5-6), 174-216 MHz (channels 7-13), 470-608 MHz (channels 14-36), and 614-698 MHz (channels 38-51). Channels 2-13 are in the very high frequency (VHF) band, and channels 14-51 are in the ultra high frequency (UHF) band. Ibid. at ¶ 1, n. 1.

[73] Federal Communications Commission. Broadcast Incentive Auction. www.fcc.gov. Available at https://www.fcc.gov/about-fcc/fcc-initiatives/incentive-auctions; Federal Communications Commission. How it Works: The Incentive Auction Explained. www.fcc.gov. Available at https://www.fcc.gov/about-fcc/fcc-initiatives/incentive-auctions/how-it-works.

[74] 2015 TVWS Report and Order at ¶ 2.

[75] Ibid.

[76] Federal Communications Commission. Incentive Auction: Forward Auction – Announcements. www.fcc.gov. Available at https://auctiondata.fcc.gov/public/projects/1000/reports/forward_announcements.

licensed services.[77] At that time, TV stations operated on six-megahertz channels, with designated channels 2 to 69 in four bands of frequencies in the VHF and UHF regions of the radio spectrum (refer to footnote 72), with UHF encompassing the 470-806 MHz band.[78] However, because of the ongoing conversion from analog to digital transmission, channels above 698 MHz (channels 52-69) would be reallocated for other uses (and would ultimately be primarily used for mobile wireless service).[79]

The rules adopted in 2008 provided for operation of two types of unlicensed TVWS devices that could provide broadband data and other types of communications services: (1) fixed devices, which would operate from a fixed location with relatively higher power and could be used to provide a variety of services including wireless broadband access in urban and rural areas, and (2) personal/portable devices, which would use lower power and could, for example, take the form of devices such as Wi-Fi-like cards in laptop computers or WLANs.[80] Fixed devices would be required to determine their geographic location through an incorporated geo-location capability or from a professional installer and to access and register with a database system that contains records of protected services and receive back either a list of the available channels at their location or information on the channels used in their area from which they could determine a list of available channels.[81] Personal/portable devices would be allowed to operate in either a client mode whereby they would be under the control of an independent device that would determine available channels, or in independent mode, whereby channel determination would work similarly to that for fixed devices.[82]

In 2010, the FCC refined rules for TVWS spectrum and TVWS devices, including, modifying protection criteria for incumbent services such as wireless microphones, eliminating certain sensing requirements, enhancing security requirements for communication between TVWS devices and TV band databases, and amending rules to protect Canadian and Mexican stations in border areas.[83] Then, in two separate orders, the FCC's Office of Engineering and Technology designated ten entities to administer white space databases: Airity, Inc.; Comsearch; Frequency Finder, Inc.; Google, Inc.;

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[77] Federal Communications Commission (2008). "Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band." Second Report and Order and Memorandum Opinion and Order in ET Docket Nos. 04-186 and 02-380. Adopted Nov. 4, 2008. Released Nov. 14, 2008. ("2008 TVWS R&O and MO&O") At ¶ 1. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-08-260A1.pdf.

[78] Ibid ¶ 12.

[79] Ibid; Federal Communications Commission. Auction 73, 700 MHz Band. www.fcc.gov. Available at http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=73.

[80] 2008 TVWS R&O and MO&O, ¶ 6.

[81] Ibid, ¶ 8.

[82] Ibid, ¶ 9.

[83] Federal Communications Commission (2010). "Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band." Second Memorandum Opinion and Order in ET Docket Nos. 04-186 and 02-380. Adopted Sep. 23, 2010. Released Sep. 23, 2010. ("2010 TVWS Second MO&O") At ¶ 3. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-10-174A1.pdf.

LS Telecom; Key Bridge Global LLC; NeuStar, Inc.; Spectrum Bridge, Inc.; iconectiv; and Microsoft Corporation.[84]

In 2014, as part of the Incentive Auction, the FCC set out to reorganize television stations in the 600 MHz band, whereby stations that remain on the air after the Incentive Auction would occupy a smaller portion of the UHF band, thereby freeing up a portion of that band for new wireless uses.[85] The FCC stipulated that TVWS devices would be permitted to operate on any unused television channels following the Incentive Auction.[86] The FCC also indicated an intent to designate an unused channel in the remaining television band in each area for shared use by wireless microphones and TVWS devices while additionally designating the 600 MHz Band guard bands for unlicensed use nationwide and permitting unlicensed channel 37 use in locations that are not used for radio astronomy facilities (RAS) and wireless medical telemetry (WMTS).[87]

The rules regarding TVWS discussed in the 2014 Incentive Auction Report and Order were updated and finalized in 2015.[88] Among other things, rule changes included increases to power limits in areas in less congested areas and 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.[89] The FCC also provided additional location and frequency information in the white space databases and made certain changes to database procedures.[90]

Service Rules and Technical Standards:

The service rules for TVWS are set out in 47 C.F.R., Part 15.[91] In particular, the relevant sections of Part 15 include Subparts A-C, except where specific provisions are

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[84] Federal Communications Commission, Office of Engineering and Technology (2011). "Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band." Order in ET Docket Nos. 04-186 and 02-380. Adopted Jan. 26, 2011. Released Jan. 26, 2011. Available at https://apps.fcc.gov/edocs_public/attachmatch/DA-11-131A1_Rcd.pdf; Federal Communications Commission, Office of Engineering and Technology (2011). "Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band." Order in ET Docket Nos. 04-186 and 02-380. Adopted Jul. 28, 2011. Released Jul. 29, 2011. Available at https://apps.fcc.gov/edocs_public/attachmatch/DA-11-1291A1_Rcd.pdf.

[85] Federal Communications Commission (2014). "Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions." Report and Order in GN Docket No. 12-268. Adopted May 15, 2014. Released Jun. 2, 2014. ("2014 Incentive Auction Report and Order") At ¶ 109. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-14-50A1.pdf.

[86] Ibid ¶ 258.

[87] Ibid.

[88] 2015 TVWS Report and Order.

[89] Ibid, ¶¶ 6, 51.

[90] Ibid, ¶¶ 9, 238, 256.

[91] Federal Communications Commission. White Space Database Administrators Guide. www.fcc.gov. Available at https://www.fcc.gov/general/white-space-database-administrators-guide; U.S. Government Code of Federal Regulations. Electronic Code of Federal Regulations.

contained in Subpart H, which specifically applies to white space devices.[92] An overview of the most pertinent rules specific to TVWS follows:

Subpart A sets out regulations under which devices that generate and emit radio frequency by radiation or induction (radiators) may be operated without an individual license,[93] including restrictions on harmful interference with authorized operations,[94] prohibitions on using devices for eavesdropping,[95] and general technical requirements.[96] This subpart also sets out, among other things, requirements regarding labelling on devices,[97] provision of information to users,[98] inspection by the FCC,[99] and various measurement standards.[100]

Subpart B specifies various additional technical rules related to unintentional radiators—devices that intentionally generate radio frequency energy for use within the device, or that sends radio frequency signals by conduction to associated equipment via connecting wiring, but which is not intended to emit RF energy by radiation or induction.[101] Subpart C similarly specifies technical rules related to intentional radiators—devices that intentionally generate and emit frequency energy by radiation or induction—including various alternatives to general radiation emission limits in specified frequency bands.[102]

Finally, Subpart H sets forth regulations for unlicensed TVWS devices—unlicensed intentional radiators that operate on available TV channels in the broadcast television frequency bands, the 600 MHz Band (including the guard bands and duplex gap), and in 608-614 MHz (channel 37).[103] These include additional labeling requirements, general technical requirements, and interference avoidance and protection measures.[104]

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www.ecfr.gov. Available at http://www.ecfr.gov/cgi-bin/text-idx?SID=a6d48809cbdf4e208259b1d039efd6d7&mc=true&node=pt47.1.15&rgn=div5.

[92] §15.701 and §15.705(a).

[93] §15.1(a).

[94] §15.5(b).

[95] §15.9.

[96] §15.15.

[97] §15.19.

[98] §15.21.

[99] §15.29.

[100] §§15.31-3, §15.35.

[101] §15.3(z).

[102] §15.3(o), §§15.217-15.257.

[103] §15.701.

[104] §§15.706, 15.709, 15.711-2. In addition to labelling requirements in Subpart A, white space devices must include the statement, “This equipment has been tested and found to comply with the rules for white space devices, pursuant to part 15 of the FCC rules. These rules are designed to provide reasonable protection against harmful interference. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications,” along with additional information regarding recourse in the case of harmful interference. §15.706(a).

In general, equipment manufacturers or vendors specializing in TVWS devices are responsible for satisfying the requirements set out in 47 C.F.R., Part 15.[105]

One notable technical requirement that is at least in part the responsibility of institutions planning to utilize TVWS spectrum rather than of equipment manufacturers/vendors concerns antenna height. In particular, Subpart H specifies that the transmit antenna height must not exceed 30 meters above ground level with even lower limits under certain circumstances.[106] However, it may be possible to justify why a waiver of this height limit would be necessary. For example, Susan Corbett, the owner and CEO of Axiom Technologies,[107] a WISP serving the State of Maine,[108] noted that because of the height of the tree line in certain areas, TVWS devices would be subject to substantial interference at the FCC's antenna height limit. As such, together with equipment manufacturer/vendor, Adaptrum, Axiom sought a waiver request to the FCC, justifying the need to mount antennas at heights as great as 250 feet above the ground.[109]

TVWS Databases (Subpart H): Before further discussing some of our findings from interviews with TVWS device vendors and other stakeholders in the TVWS ecosystem, it is worth elaborating on TVWS database administration as it is set out in the rules. With the exception of TVWS devices that are permitted to rely solely on spectrum sensing by demonstrating with an extremely high degree of confidence that they will not cause harmful interference to incumbent radio services, channel availability for a TVWS device is determined based on the geo-location and database access methods described in §15.711 (in Subpart H).[110]

White space devices must rely on a geo-location capability and database access mechanism to protect digital television stations, translator and booster stations, translator receive operations, fixed broadcast auxiliary service links, RAS and WMTS, 600 MHz service band licensees where they have commenced operations, and various other services.[111]

Geo-location for fixed TVWS devices needs to be accurate (in accordance with §15.711(b)(1)) and coordinates must be referenced to the North American Datum of 1983 (NAD 83).[112] The geographic coordinates and antenna height above ground level

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[105] Additional information regarding FCC equipment authorization is available from the FCC at https://www.fcc.gov/engineering-technology/laboratory-division/general/equipment-authorization.
[106] §15.709(g).
[107] Phone interview with Susan Corbett on Aug. 15, 2016.
[108] More information about Axiom Technologies is available at http://connectwithaxiom.com/.
[109] 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.
[110] See additionally, §15.717.
[111] §15.711(a).
[112] §15.711(b); National Geodetic Survey. CORS Coordinates. http://geodesy.noaa.gov/. Available at http://geodesy.noaa.gov/CORS/coords.shtml.

must be determined at the time of installation and first activation from a power-off condition by either an incorporated geo-location capability or a professional installer and this information must be registered with a database.[113] Each fixed white space device must access a white space database over the Internet to determine the available channels and the corresponding maximum permitted power for each available channel that is available at its geographic coordinates, taking into consideration the fixed device's antenna height above ground level and geo-location uncertainty, prior to its initial service transmission at a given location.[114] Operation is permitted only on channels and at power levels that are indicated in the database as being available for each white space device[115] and the database must be accessed at least once a day to verify that the operating channels continue to remain available.[116]

Similar requirements are also specified for Mode II and Mode I personal/portable TVWS devices, though the requirements are somewhat different due to such devices' mobility.[117] A Mode II device is a personal/portable device that uses an internal geo-location capability and access to a white space database, either through a direct connection to the Internet or through an indirect connection to the Internet by way of fixed device or another Mode II device, to obtain a list of available channels.[118] A Mode I device is a personal/portable white space device that does not use an internal geo-location capability and access to a white space database to obtain a list of available channels.[119] A Mode I device must obtain a list of available channels on which it may operate from either a fixed white space device or Mode II personal/portable white space device.

TVWS devices must also incorporate the capability to display a list of identified available channels and its operating channels,[120] they must transmit identifying information,[121] and among other things, incorporate adequate security measures to ensure that they are capable of communicating for purposes of obtaining lists of available channels only with databases operated by administrators authorized by the FCC.[122]

Section 15.713 in Subpart H outlines the functions of white space databases, the specifics of which we do not elaborate on here. Additional information on white space databases is available at the FCC Website.[123] This includes a brief overview of the selection of designated database administrators as laid out in the FCC's Office of

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[113] §15.711(c)(1); §15.711(c)(1)(ii).
[114] §15.711(c)(2)(i).
[115] §15.711(c)(2)(ii).
[116] §15.711(c)(2)(iii).
[117] §15.711(d)-(e). For instance, the location of Mode II devices must be checked at least once every 60 seconds while in operation, except while in sleep mode. §15.711(d)(1).
[118] §15.703(i).
[119] §15.703(j).
[120] §15.711(f).
[121] §15.711(g).
[122] §15.711(j).
[123] Federal Communications Commission. White Space Database Administrators Guide. www.fcc.gov. Available at https://www.fcc.gov/general/white-space-database-administrators-guide.

Engineering and Technology orders mentioned above. Importantly, the website lists contact information for database administrators as well as their approval status with regard to submissions claiming to comply with FCC requirements ensuring consistency and compliance with database rules.

Discussion:

As part of our research on TVWS, we engaged in interviews with individuals representing entities throughout the white space ecosystem. The discussions included conversations with representatives of educational and other community anchor institutions (CAIs) seeking to rely on TVWS to offer service to surrounding communities as well as with various equipment manufacturers/vendors and firms involved in providing service using white spaces. Whereas a detailed discussion regarding what we have learned from talking with CAI representatives can be found in the accompanying business strategy and case analysis, here, we focus on the takeaway from our conversations with equipment vendors and other firms involved in facilitating the use of TVWS for broadband access.

We interviewed representatives from three separate equipment vendors, including Robert Wu, Founder and CEO of 6Harmonics (phone interview on Aug. 18, 2016); Hanxi Chen, Vice President of Products and Solutions at Adaptrum (phone interview on Aug. 31, 2016); and Jim Carlson, Founder and CEO of Carlson Wireless (phone interview on Aug. 30, 2016).[124] In addition to also interviewing representatives of certain CAIs, we spoke with Don Means, Co-Founder and Principal of Digital Village Associates (phone interview on Aug. 25, 2016 and numerous additional conversations), a consulting enterprise focusing on information and communication technologies that is presently collaborating on the Gigabit Libraries Network White Space project[125] as well as with William Seiz, President of TV Band Service (TVBS; phone interview on Aug. 25, 2016), whose subsidiaries, URcast Network and Final Mile Communications respectively develops caching software and facilitate distribution of TVWS equipment to communities.[126]

As suggested by Don Means, to a degree, television white space spectrum enables “DIY” (do it yourself) infrastructure. Because the spectrum is unlicensed, the major hurdle for equipment manufacturers is to certify equipment with the FCC. Thus, to set up a network, all that institutions with access to backhaul need to do to extend the reach of their networks using TVWS spectrum and devices is to obtain and set up FCC certified equipment such as that available from the manufacturer/vendors whom we interviewed, subject to certain limits, such as those on antenna height.

Moreover, because of its low frequency, this spectrum does not require line-of-sight between a base station and the user (though naturally, as with all spectrum bands,

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[124] Company websites for these vendors are respectively: http://www.6harmonics.com/, http://www.adaptrum.com/, and http://www.carlsonwireless.com/.

[125] See Digital Village Associates. Projects. http://www.digitalvillage.com/projects.html; Gigabit Libraries Network. http://giglibraries.net/.

[126] Company websites for TV Band Service, URcast, and Final Mile Communications are respectively: http://tvbandservice.com/, http://www.urcastnetwork.com/, http://finalmilecommunications.com/.

efforts to minimize barriers such as those undertaken by Axiom Technologies could improve performance), which in part explains its association with the term, "Super Wi-Fi."[127] As is the case with spectrum used for mobile wireless communication base stations, TVWS antennas can be omnidirectional, though devices at the point of connection to the user may be directional antennas focused specifically on the base station.

It is worth noting that most TVWS deployments undertaken to date have remained dependent on Wi-Fi for their final connection to end user devices. For instance, a TVWS device (such as say a hotspot) might consist of a directional antenna that communicates with a base station using the 802.11af TVWS standard[128] and a separate standard Wi-Fi component that communicates with consumer devices. This contrasts with spectrum used for mobile wireless service, including EBS, which can communicate directly to users in possession of portable devices equipped with SIM cards that support LTE Band 7 or 41.[129] Although our conversations with vendors indicated that TVWS equipment introduced in the coming year will have smaller footprints and lower cost than earlier generations, it is not clear yet when (or even if) TVWS components will be small and inexpensive enough to be integrated into portable devices like laptops, tablets, and smartphones.

In spite of the benefits of TVWS spectrum, including the benefits that derive from its low frequency (high wavelength) and lack of licensing requirements, TVWS faces a number of drawbacks at the present. First, the wireless applications of TVWS are fairly novel, with adoption potentially hampered by lack of microchip availability from large fabrication companies, with Taiwanese firm MediaTek being the only major semiconductor company presently working in this space.[130] A somewhat related concern is that there is currently no market based solution for interference when two TVWS devices attempt to utilize the same available channel simultaneously, a possibility if there are few channels available, and particularly if devices additionally employ sensing capabilities to choose the optimal channel based on a combination of throughput, signal level, and link quality. Currently, a device with greater power will dominate, forcing the competing device to rely on a different frequency. However, in the

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[127] See e.g., Segan, S. (2012, Jan. 27). "'Super Wi-Fi': Super, But Not Wi-Fi." *PCMag*. Available at http://www.pcmag.com/article2/0,2817,2399447,00.asp.

[128] For a brief discussion of the different 802.11, see Triggs, R. (2016, Jan. 8), "WiFi standards explained: what you should know about the new 802.11 ad, ah & af standards." Android Authority. Available at http://www.androidauthority.com/wifi-standards-explained-802-11b-g-n-ac-ad-ah-af-666245/. See also, http://www.androidauthority.com/wp-content/uploads/2016/01/WiFi-distances-compared.jpg. The designation 802.11 refers to the family of IEEE standards around which most WLANs are built. See Dodd, A.Z. (2012), Supra n. 21 at 365-368; IEEE802. IEEE 802 LAN/MAN Standards Committee. http://www.ieee802.org/. Available at http://www.ieee802.org/.

[129] As an example, Sprint, which controls substantial BRS and EBS spectrum relies on Band 41 devices. See e.g., 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.

[130] See http://www.mediatek.com/en/.

future, dynamic auction mechanisms might be used to allocate the channel to a bidder that values it more in real time.[131]

Additionally, the ongoing Incentive Auction creates a degree of uncertainty regarding the potential future availability of TVWS spectrum. This concern is however somewhat mitigated by the rules set out in the 2015 TVWS Report and Order referenced above. Most vendors whom we spoke with, as well as representatives from Microsoft,[132] which has partnered with network operators in the United States and abroad on various white space projects to provide low cost solutions for broadband, believe that white space availability will not diminish substantially in the foreseeable future, particularly in more rural areas.

Finally, perhaps the largest drawback of TVWS spectrum is simply the lack thereof. This is an issue faced by other low frequency bands, often termed beachfront spectrum for their desirability. Thus, although this spectrum is notable for its strong propagation characteristics, the short supply of this spectrum makes it incapable of providing anything close to the Gigabit-level backhaul available from some of the shorter wavelength bands discussed elsewhere in this report.

2.3. Fixed Microwave Services

Microwaves are short waves used mostly for point-to-point communications systems.[133] Much of the technology was derived from radar developed during World War II.[134] Initially, these systems carried multiplexed speech signals over common carrier and military communications networks, whereas today they can handle voice and data in either an analog or digital format.[135] However, at the current state of technology, the higher frequency of fixed microwave spectrum makes it less appropriate for the type of geographic licensing applied to EBS or the type of omnidirectional devices that rely on TVWS. Rather, broadband service providers often use microwave links as a cost-effective alternative to traditional copper circuits and fiber optic links.[136] As we

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[131] Research exploring such auction mechanisms is underway at Michigan State University. For instance, see Hyder, C.S., Jeitschko, T.D., Xiao, L. (2015). Towards a truthful online spectrum auction with dynamic demand and supply. *Proceedings - IEEE Military Communications Conference MILCOM*. Vol. 2015-December, 413-418.

[132] Phone interview with Paul Garnett, Director in Microsoft's Technology Policy Group and Sid Roberts, Principal Program Manager, on Aug. 31, 2016.

[133] Federal Communications Commission. Fixed Microwave Services. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=service_home&id=microwave.

[134] Ibid.

[135] Ibid.

[136] Federal Communications Commission (2011). "Amendment of Part 101 of the Commission's Rules to Facilitate the Use of Microwave for Wireless Backhaul and Other Uses and to Provide Additional Flexibility to Broadcast Auxiliary Service and Operational Fixed Microwave Licensees et al." Report and Order, Further Notice of Proposed Rulemaking, and Memorandum Opinion and Order in WT Docket No. 10-153 et al. Adopted Aug. 9, 2011. Released Aug. 9, 2011. ("2011 Fixed Microwave R&O et al.") At ¶ 1. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-11-120A1_Rcd.pdf.

mentioned toward the start of this report, in certain rural and remote locations, microwave is the only practical high-capacity backhaul solution available.[137]

Although fixed microwave services include various bands ranging from below 1 GHz all the way to bands with millimeter wavelengths our interviews and discussion focuses on what to our knowledge are the most commonly used fixed microwave bands: 6 GHz, 11 GHz, 18 GHz, and 23 GHz.[138] In the next section discussing Millimeter Waves, we elaborate on spectrum in frequencies above 70 GHz, which is regulated similarly to the bands discussed here.

In general, spectrum below 13 GHz is preferred for long-link backhaul because signals can overcome the rain fading effects that limit transmission distances at higher frequencies.[139] However, bands above 13 GHz have been increasingly used for shorter distance backhaul.[140] Moreover, in the past decade, the FCC has updated the rules contained in 47 C.F.R., Part 101 to establish directional antenna standards and allow wider channels designed to maximize use of microwave spectrum, avoid interference, and increase maximum throughput.[141]

History:

In 1963, the FCC reallocated certain microwave bands to the Safety and Special Radio Services, ending the necessity for private users to share those frequencies with common carriers.[142] Provisions for microwave operations were added to the rule parts governing Marine, Aviation, Public Safety, Industrial, and Land Transportation Radio Services.[143] The FCC consolidated and updated those provisions into 47 C.F.R., Part 94 in 1975, creating the Private Operational-Fixed Microwave Service (POFS).[144] Whereas common carrier microwave stations are licensed to applicants who intend to provide communications service to the public, POFS stations are licensed to applicants for their own internal communications requirements.[145]

In the following decades, a number of rulemaking proceedings led to the convergence of technical standards for the common carrier (regulated under Part 21) and POFS services.[146] Additionally, because of emerging technologies, spectrum reallocation, and the resulting increase in frequency band-sharing, common carrier and private

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[137] Ibid.
[138] More precisely, the bands are 5925-6875 MHz (6 GHz), 10.7-11.7 GHz (11 GHz), 17.7-18.8 GHz (18 GHz), and 21.2-23.6 GHz (23 GHz).
[139] 2012 Fixed Microwave R&O et al. at ¶ 5.
[140] Ibid. ¶ 5 and n. 7.
[141] 2012 Fixed Microwave R&O et al.
[142] Federal Communications Commission. About Fixed Microwave Service. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=about&id=microwave.
[143] Ibid.
[144] Ibid.
[145] Ibid.
[146] Federal Communications Commission (1996). "Reorganization and Revision of Parts 1, 2, 21, and 94 of the Rules to Establish a New Part 101 Governing Terrestrial Microwave Fixed Radio Services, et al." Report and Order in WT Docket No. 94-148 et al. Adopted Feb. 8, 1996. Released Feb. 29, 1996. ("1996 Fixed Microwave Report and Order") At ¶ 2. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-96-51A1.pdf.

microwave industry members united to develop joint interference standards and coordination procedures for Part 21 and 94 users.[147] For these and other reasons, in 1996, the FCC reorganized and revised Parts 21 and 94 of the C.F.R. to establish a new Part 101.[148]

The reorganization included the elimination of certain showings previously required of common carrier microwave applicants, including requirements to file a financial showing, public interest statement, and site availability showing; elimination of a time limit for consummating an assignment or transfer of control for common carrier applicants to conform with POFS; elimination and consolidation of ownership information forms; and the adoption of a ten-year license term for all Part 101 licensees.[149] It also involved changes to operational requirements, including permission for common carriers to begin station construction prior to receiving a license or filing a license application, permission for applicants to operate while their formal license applications are being processed for certain bands, and conforming the facility construction period required of license recipients to 18 months.[150] Finally, the organization consolidated technical standards, including adopting the same coordination procedures and interference standards to both common carrier and private operational fixed users and eliminating inconsistency in antenna standards.[151]

In summary, the FCC's licensing regime for common carrier and POFS requires frequency coordination and the filing of an application for each microwave link or path containing detailed information concerning the proposed operation.[152] The frequency coordination process consists of giving prior notice to nearby licensees and applicants of the proposed operations, making reasonable efforts to avoid interference and resolve conflicts, and certifying that the proposed operation has been coordinated.[153] In order to secure authorizations, applicants must specify the latitude and longitude of the transmitter in their applications to an accuracy of one second, coordinate each operation specifying the transmitter location to an accuracy of one second, and modify the license and coordinate any change to the location of the transmitter of more than five seconds in latitude or longitude or both.[154] Applicants may choose to undertake the coordination process through a third-party frequency coordinator, a list of which is available on the FCC Website (see also the National Spectrum Management

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[147] Ibid ¶ 3.
[148] Ibid ¶ 5.
[149] Ibid ¶¶ 9, 12, 17, 20.
[150] Ibid ¶¶ 26, 33.
[151] Ibid ¶¶ 65, 70.
[152] Federal Communications Commission (2010). "Amendment of Part 101 of the Commission's Rules to Facilitate the Use of Microwave for Wireless Backhaul and Other Uses and to Provide Additional Flexibility to Broadcast Auxiliary Service and Operational Fixed Microwave Licensees, et al." Notice of Proposed Rulemaking and Notice of Inquiry in WT Docket No. 10-153 et al. Adopted Aug. 5, 2010. Released Aug. 5, 2010. ("2010 Fixed Microwave NPRM and NOI") At ¶ 6. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-10-146A1_Rcd.pdf.
[153] Ibid at ¶ 7.
[154] Ibid.

Association).[155] However, in contrast to designated databases that are required to be used for TVWS frequency coordination, the FCC does not license or endorse microwave frequency coordinators.[156]

Over the last decade, the FCC updated a number of rules related to the 6 GHz, 11 GHz, 18 GHz, and 23 GHz bands. In 2007, the FCC amended the applicable parts of Part 101 to permit installation of smaller (effectively, 0.61 meter) antennas in the 11 GHz band, which is allocated within the United States on a co-primary basis to Fixed (microwave) Services (FS) and to Fixed Satellite Service (FSS).[157] Similarly, in 2012, the FCC permitted smaller antenna standards for the 6 GHz, 18 GHz, and 23 GHz bands; standards which would permit three-foot, one-foot, and eight-inch antennas for the three bands respectively.[158] Smaller antennas lower installation costs, allow existing towers to accommodate more antennas, and allow installation at sites that would not otherwise be able to accommodate larger antennas, albeit at the risk of potentially causing greater interference.[159] Under the new rules, if smaller antennas would cause an interference conflict with another applicant or licensee, the applicant proposing the smaller antenna must upgrade its antenna.[160]

An additional rule change that occurred in 2012 was the Rural Microwave Flexibility Policy, which was designed to provide operators relief, though the FCC waiver process, from the efficiency standards that may not be necessary in noncongested rural areas.[161] This change was intended to facilitate the use of microwave backhaul in rural areas by allowing substantial cost savings in deployment.[162] In the same report and order, the FCC also allowed FS operators to combine adjacent channels in the lower 6 GHz band (5925-6425 MHz) and 11 GHz band respectively, to form 60 and 80 megahertz wide channels (double the previous limits).[163]

Licensing and Technical Standards:

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[155] Federal Communications Commission. Fixed Microwave Services. Frequency Coordinators. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=licensing_1&id=microwave; National Spectrum Management Association (NSMA). www.nsma.org.
[156] Federal Communications Commission. Fixed Microwave Services. Frequency Coordinators. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=licensing_1&id=microwave.
[157] Federal Communications Commission (2007). "Amendment of Part 101 of the Commission's Rules to Modify Antenna Requirements for the 10.7-11.7 GHz Band, et al." Report and Order in WT Docket No. 07-54, RM-11043. Adopted Sep. 7, 2007. Released Sep. 10, 2007. ("2007 Fixed Microwave Report and Order"). Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-07-163A1.pdf.
[158] 2012 Fixed Microwave R&O et al. at ¶¶ 10, 18. Note that in each case, antenna sizes refer to category (or standard) B antennas which are more likely to cause harmful interference than larger category-A antennas.
[159] Ibid at ¶ 18.
[160] Ibid.
[161] Ibid. at ¶ 37.
[162] Ibid.
[163] Ibid. at ¶¶ 47, 52.

The service rules for fixed microwave services are set out in 47 C.F.R., Part 101, the bulk of which are set out in Subparts B-D, and with Subparts E, H, I laying out additional common carrier and POFS provisions.[164] An overview of the most pertinent rules specific to the FS bands follows:

Applications and Licenses (Subpart B): Subpart B contains the relevant application and license rules and requirements that have been described in the FS History subsection of Section 2.3. This includes station authorization requirements,[165] restrictions on foreign license ownership,[166] technical information that must be included in a license application,[167] and rules governing operation of service at temporary locations.[168] Licenses for stations authorized under Part 101 are issued for a period not to exceed 10 years.[169]

The FCC considers applications to be mutually exclusive if their conflicts are such that the grant of one application would effectively preclude by reason of harmful electrical interference, or other practical reason, the grant of one or more of the other applications.[170] Sections 101.45 and 101.51 set out when an application is entitled to comparative consideration with one or more conflicting applications and how such applications are compared and evaluated.

An additional section contained in Subpart B concerns the transition period during which fixed-satellite service licensees may relocate existing FS licensees in the 18.3-19.3 GHz band.[171] In particular, with regard to the 18 GHz band, in 2000 the FCC designated for terrestrial fixed service use the 17.7-18.3 GHz band on a primary basis and the 18.3-18.58 GHz band on a co-primary basis (with FSS).[172] The FCC also designated the 18.58-18.8 GHz band on a primary basis for FSS use.[173] The FCC intended these designations to reduce sharing in the 18 GHz band and eliminate the need for many

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[164] 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=1674cb97084f1ca0d0b07778412e1959&mc=true&node=pt47.5.101&rgn=div5.

[165] §101.5. Station authorization requirements include, for instance, the rule that common carrier and POFS station construction may be initiated prior to grant of an authorization.

[166] §101.7

[167] §101.21.

[168] §101.31.

[169] §101.67.

[170] §101.45(a).

[171] 47 C.F.R., Part 101, Subpart B, Policies Governing Fixed Service Relocation from the 18.58-19.30 GHz Band. Available at http://www.ecfr.gov/cgi-bin/text-idx?SID=2369529143e99c8ebd7960caa087f6ec&mc=true&node=sp47.5.101.b&rgn=div6#sg47.5.101_182.sg3.

[172] Federal Communications Commission (2000). "Redesignation of the 17.7-19.7 GHz Frequency Band, Blanket Licensing of Satellite Earth Stations in the 17.7-20.2 GHz and 27.5-30.0 GHz Frequency Bands, and the Allocation of Additional Spectrum in the 17.3-17.8 GHz and 24.75-25.25 GHz Frequency Bands for Broadcast Satellite-Service Use." Report and Order in IB Docket No. 98-172, RM-9005, RM-9118. Adopted Jun. 8, 2000. Released Jun. 22, 2000. ("2007 Fixed Microwave Report and Order"). At ¶ 4. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-00-212A1.pdf.

[173] Ibid.

coordination procedures existing at that time.[174] Section 101.85 stipulates that FSS licensees may negotiate with FS licensees authorized to use frequencies in the 18.3-19.30 GHz bands for the purpose of agreeing to terms under which the FS licensees would relocate to other frequency bands, media or facilities; accept a sharing arrangement with the FSS licensee; or in the event that no agreement is reached, potentially be forced to relocate.

Technical Standards (Subpart C): Subpart C specifies the frequencies available for FS services[175] and lays out frequency coordination procedures[176] and various technical rules. The crux of the rules here relies on the fact that the FCC assigns frequencies only in such a manner as to facilitate interference-free communication in each service area.[177] Our focus in this report is on rules that may entail direct action by an FS licensee, and not on technical requirements governing equipment, the responsibility for which would largely fall on equipment manufacturers or vendors. Thus, we do not elaborate further on interference protection criteria,[178] emission limitations,[179] power limitations,[180] or authorization of transmitters.[181]

Section 101.115 sets out rules for directional antennas. Unless otherwise authorized upon specific request by the applicant, each station must employ a directional antenna adjusted with the center of the major lobe of radiation in the horizontal plane directed toward the receiving station with which it communicates.[182] Most fixed stations must employ transmitting and receiving antennas (excluding second receiving antennas for operations such as space diversity)[183] meeting an appropriate (antenna) performance standard, denoted Standard A, except that in areas not subject to frequency congestion, antennas meeting a lower performance standard, denoted Standard B, may be used.[184] Section 101.115(c) stipulates that a Standard B antenna user must upgrade to Standard A if the antenna causes interference problems that would be resolved by the use of a Standard A antenna.[185]

An applicant must determine, prior to filing an application for a radio station authorization, that the antenna site specified therein is adequate to render the proposed service.[186] In cases of questionable antenna locations, propagation tests are desired and the FCC may require site survey tests.[187] Equipment at the operating and transmitting positions must be installed and protected as not to be accessible to, or

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[174] Ibid.
[175] §101.101.
[176] §101.103.
[177] §101.103(a).
[178] §101.105.
[179] §101.111.
[180] §101.113.
[181] §101.139.
[182] §101.115(a).
[183] As we discuss below, space diversity may be necessary in the 6 GHz band.
[184] §101.115(b).
[185] 2012 Fixed Microwave R&O et al. at ¶¶ 9.
[186] §101.129(a).
[187] Ibid.

capable of being operated by persons other than those authorized by the licensee.[188] Section 101.131 sets out additional transmitter construction and installation requirements and Section 101.133 specifies limitation on transmitter use.

Section 101.141 specifies a minimum bit rate and payload capacity to ensure that FS links are operated efficiently. Bit rate is defined as the rate of transmission of information in binary form in bits per unit time and payload capacity is the bit rate available for transmission of data excluding overhead data generated by the system.[189] In particular, with some exceptions, the bit rate must be equal to or greater than the bandwidth specified by the emission designator in Hertz (e.g., to be acceptable, equipment transmitting at a 20 Mb/s rate must not require a bandwidth of greater than 20 MHz).[190] Minimum efficiency standards for payload capacity are specified in §101.141(a)(3)(i). Additionally, Part 101 specifies minimum path length requirements, where path length is the total distance of a path from the transmit to the receive antenna.[191]

Operational Requirements (Subpart D): Licensees of each station authorized in the radio services included in Part 101 must make the station available for inspection by FCC representatives.[192] Communications concerning safety of life and property must be afforded priority over other messages.[193] Licensees of any station may utilize them for emergency communication (subject to certain stipulations).[194] Transmission must be suspended immediately upon detection by the station or operator licensee or upon notification by the Commission of a deviation from the technical requirements of the station authorization and must remain suspended until such deviation is corrected, except for transmission concerning the immediate safety of life or property.[195] Other sections included in Subpart D concern temporary fixed locations for communication between the U.S. and Canada or Mexico (§101.209) and station identification and records (§101.213, §101.217).

Discussion:

While researching the use of fixed microwave services, we interviewed representatives from a number of companies that deploy FS as part of or to complement their other services. Individuals included Susan Corbett of Axiom Technologies (discussed above); Michael Hutter, Head of National Wireless Sales at MapleNet Wireless (phone interview on Aug. 17, 2016), which engineers and deploys high capacity microwave wide area networks;[196] and representatives from Cruzio Internet, a Competitive Local Exchange Carrier (CLEC) discussed further in Section 2.4. We also spoke with a number of executives at CostQuest Associates, a business consultancy that performs pricing, cost,

[188] §101.131(a).
[189] §101.3.
[190] §101.141(a)(1).
[191] §101.143; §101.3.
[192] §101.201.
[193] §101.203(a).
[194] §101.205.
[195] §101.207.
[196] The company website is http://www.maplenetwireless.com/.

business case and management analysis, with substantial expertise in telecommunications and telecommunications regulation.[197]

Unlike the bands discussed in the previous subsections, the various FS bands rely on a line-of-sight connection between "points." Although each of the FS bands described here is suitable for wireless backhaul, a major tradeoff among these bands is between maximum throughput and distance, with bandwidth (maximum throughput) generally increasing and distance falling at higher frequencies. This is in part driven by the decrease in wavelength (faster attenuation) and greater availability of spectrum at higher frequencies. However, we note that although this relationship happens to hold among the FS bands discussed here, it is not necessarily monotonic across the board and is impacted by factors such as transmission power limits.

Interviewees indicated that the 6 GHz band could be used to establish backhaul connections going 20 miles or further. A major hurdle at this distance is the curvature of the earth, which requires sufficient tower height for the Fresnel zone to clear earth terrain.[198] Additionally, a "long-haul" using the 6 GHz band such as this might require space diversity that could be achieved for instance by having a separate transmit and receive antennas on each end of the link, which could substantially increase the cost of installation.[199] Interviewees have noted that throughput on such links can be 400 Mbps per radio, though this can be doubled or more, by stacking radios. Typical antenna sizes may include 6 or even 12 feet, which is substantially bigger than the three-foot category-B antennas permitted for this band by the FCC.

Although interviewees differed in the maximal throughput and distances achieved by the 11 GHz, 18 GHz, and 23 GHz bands, all generally concurred with regard to the distance versus bandwidth tradeoff. Using 11 GHz, interviewees had achieved Gigabit bandwidth spanning 10 miles, though longer links with less throughput had also been set up. The 23 GHz band is typically used for shorter distances (say 2-3 miles) to provide what is typically Gigabit bandwidth, though bandwidth can be raised substantially (to say 4 Gbps). However, this band may see less use in the future, because of technological developments and spectrum availability in the millimeter wave bands discussed below.

Ultimately, as our discussion with CostQuest Associates confirmed, the decision to substitute a wireline deployment with fixed microwave spectrum boils down to cost. As we discuss in greater depth in the accompanying business strategy and case analysis, for a greenfield deployment, if one excludes the cost of equipment, the appropriate comparison is the per mile cost to run fiber with the cost of all links in an FS

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[197] The company website is http://www.costquest.com/. In particular, on Sept. 7, 2016, we conducted a phone interview with James Stegeman, President; Mike Wilson, Vice President of Sales and Professional Services; and Ron Williams, Director, Economic Models.

[198] See Richards (2008), supra n. 21 at 47-48; Seybold (2005), supra n. 21 at §8.2.2. Fresnel zones are concentric ellipsoids surrounding and centered on a transmission path. If the transmitting antennas are viewed as foci, the first Fresnel zone is described by the locus of a point that is one half wavelength greater than the distance between the antennas. Objects that lie outside the first Fresnel zone are said to have Fresnel zone clearance; they are then assumed to have little effect on the forward energy carried by the transmission.

[199] Space diversity might, for instance, be necessary for a long link over water, where reflections from the water could cause multipath signals that interfere with the direct signal.

deployment, which includes site identification, acquisition and development, permitting, and licensing, the latter of which is generally relatively insubstantial for FS licenses.

2.4. Millimeter Waves

The term "millimeter wave" derives from the wavelength of radio signals on frequencies between 30 GHz and 300 GHz, which ranges between 1 and 10 millimeters.[200] At these frequencies, radio signals attenuate more rapidly with distance than at the lower frequencies discussed elsewhere in this report. However, as the FCC recently noted in its Spectrum Frontiers Report and Order, "technological advances hold promise for potentially unlocking millimeter wave (mmW) bands for mobile and other operations in a way that meets the need for flexible access to spectrum to improve bandwidth in constrained geographies."[201]

Whereas the rapid signal attenuation of mmW transmissions might appear to be a major disadvantage for many applications, it does allow the reuse of frequencies within very short distances and, thereby enables a higher concentration of transmitters to be located in a geographical area than is possible at lower frequencies.[202] Moreover, where longer paths are desired, the extremely short wavelengths of mmW signals make it feasible for very small antennas to concentrate signals into highly focused beams with enough gain to overcome propagation losses.[203] The short wavelengths of mmW signals also make it possible to build multi-element, dynamic beam-forming antennas that will be small enough to fit into handsets.[204]

Although in our interviews with stakeholders and practitioners who presently rely on mmW spectrum for high speed broadband Internet service we have focused on fixed wireless, high throughput, but low distance applications, recent developments suggest that mobile deployment using mmW spectrum is not too far off. Thus, although for concision, we largely focus the discussion on the unlicensed mmW spectrum in the 57-71 GHz frequency range (alternatively referred to as V-band or 60 GHz spectrum) and licensed spectrum in the 71-76 GHz, 81-86 GHz, and 92-95 GHz ranges (alternatively, E-band or 70/80/90 GHz), at the end of Section 2, we discuss recent FCC actions to designate additional mmW spectrum for mobile wireless and other use under novel licensing regimes (see discussion of Spectrum Frontiers).

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[200] Wavelength, λ, in meters, is calculated by the formula λ =C/F, where C is the speed of light (3×10^8 meter/second) and F is the frequency in Hertz. Federal Communications Commission. Millimeter Wave 70/80/90 GHz Service. www.fcc.gov. Available at https://www.fcc.gov/wireless/millimeter-wave-708090-ghz-service.

[201] Federal Communications Commission (2016). "Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, et al." Report and Order and Further Notice of Proposed Rulemaking in GN Docket No. 14-177, et al. Adopted Jul. 14, 2016. Released Jul. 14, 2016. ("2016 Spectrum Frontiers R&O and FNPRM") At ¶ 6. Available at https://www.fcc.gov/document/spectrum-frontiers-ro-and-fnprm.

[202] Federal Communications Commission. Millimeter Wave 70/80/90 GHz Service. www.fcc.gov. Available at https://www.fcc.gov/wireless/millimeter-wave-708090-ghz-service.

[203] 2016 Spectrum Frontiers R&O and FNPRM at ¶ 6.

[204] Ibid.

60 GHz Band:

In 1995, the FCC envisioned that the 59-64 GHz band offered the greatest potential for allowing the development of short-range wireless radio systems with communications capabilities approaching those achievable with coaxial and optical fiber cable at that time.[205] The FCC made the band available for use by general unlicensed devices under Part 15 of its rules (that is, 47 C.F.R., Part 15).[206] At the time, the FCC believed that licensing was not necessary because of the limited potential for interference due to oxygen absorption and the narrow beamwidth of point-to-point antennas likely to operate in that range.[207] In particular, higher frequency signals are significantly affected by the presence of oxygen and water vapor within the atmosphere with absorption peaks at 24 GHz for water vapor and 60 GHz for oxygen.[208]

Implementation of the FCC rules was delayed at the request of industry to provide additional time for industry to develop and submit a spectrum etiquette that would ensure that the spectrum is used effectively and efficiently.[209] The etiquette, adopted in 1998, included a coordination channel in the 59.0-59.05 GHz band, a transmission identification requirement, and a peak emissions limit.[210] In 2000, the FCC added the 57-59 GHz band to the 60 GHz spectrum already available for use by Part 15 unlicensed devices to be operated under the same rules as the 59-64 GHz band.[211]

In 2007 the FCC proposed, and in 2013 adopted modifications to the rules guiding operation in the 57-64 GHz band, allowing, among other things, higher emission limits for 60 GHz devices that operate outdoors with very high gain antennas to encourage

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[205] Federal Communications Commission (1995). "Amendments of Parts 2, 15, and 97 of the Commission's Rules to Permit Use of Radio Frequencies Above 40 GHz for New Radio Applications." First Report and Order and Second Notice of Proposed Rule Making in ET Docket No. 94-124, RM-8308. Adopted Dec. 15, 1995. Released Dec. 15, 1995. ("1995 mmW R&O and NPRM") At ¶ 14. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-95-499A1.pdf.

[206] Ibid ¶ 33.

[207] Ibid.

[208] Federal Communications Commission, Office of Engineering and Technology (1997). "Millimeter Wave Propagation: Spectrum Management Implications." Bulletin Number 70. July, 1997. ("1997 OET mmW Bulletin") At p. 2. Available at https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet70/oet70.pdf

[209] Federal Communications Commission (1998). "Amendments of Parts 2, 15, and 97 of the Commission's Rules to Permit Use of Radio Frequencies Above 40 GHz for New Radio Applications." Third Report and Order in ET Docket No. 94-124, RM-8308. Adopted Jul. 6, 1998. Released Jul. 15, 1998. ("1998 mmW Report and Order") At ¶ 3. Available at http://www.fcc.gov/Bureaus/Wireless/Orders/1998/fcc98142.wp.

[210] Ibid at ¶ 10.

[211] Federal Communications Commission (2000). "Amendment of Parts 2 of the Commission's Rules to Allocate Additional Spectrum to the Inter-Satellite, Fixed, and Mobile Services and to Permit Unlicensed Devices to Use Certain Segments in the 50.2-50.4 GHz and 51.4-71.0 GHz Bands." Report and Order in ET Docket No. 99-261. Adopted Dec. 9, 2000. Released Dec. 22, 2000. ("2000 mmW Report and Order") At ¶ 2. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-00-442A1.pdf.

broader deployment of point-to-point broadband systems.[212] The new rules would enable longer communication distances for unlicensed 60 GHz point-to-point systems, extending their ability to provide broadband service, particularly to office buildings and commercial facilities.[213]

Finally, in 2016, as part of its Spectrum Frontiers Report and Order, the FCC authorized operations in the 64-71 GHz band under Part 15 of its rules based on the rules adopted in its 2013 mmW Report and Order.[214] The FCC's action thereby creates a 14-gigaherz segment of contiguous spectrum in these frequency bands, potentially permitting very high throughput point-to-point connectivity.

Service Rules (Part 15, Subparts A-C): Many of the service rules and technical requirements discussed in Part 15, Subparts A-C of the C.F.R. apply to the mmW spectrum in the 57-71 GHz band. We do not repeat our general summary of those subparts here. The most relevant section for the 60 GHz band is §15.255, specifically laying out the rules for that band, including certain prohibitions on operation, emissions limits, and peak power levels.

70/80/90 GHz Bands:

In 2003 the FCC reallocated the 71-76 GHz, 81-86 GHz, and 92-95 GHz mmW bands for use under its Part 15 and 101 Rules.[215] The 71-76 GHz and 81-86 GHz were divided into four unpaired 1.25 gigahertz segments each (eight total) that could be aggregated without limit.[216] In total, non-Federal Government licensees received non-exclusive nationwide licenses authorizing operation on 12.9 gigahertz of co-primary spectrum. Rights with regard to specific (point-to-point) links would be established based upon the date and time of link registration. The 2003 mmW Report and Order envisioned that coordination of non-Federal Government links with Federal Government operations would eventually be accomplished via an automated mechanism administered by the National Telecommunications and Information Administration based on a framework to be agreed upon by the FCC and NTIA.[217] Additionally, with regard to the 92-95 GHz band, unlicensed non-Federal Government indoor use was permitted according to the

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[212] Federal Communications Commission (2007). "Revision of the Commission's Rules Regarding Operation in the 57-64 GHz Band." Notice of Proposed Rule Making in ET Docket No. 07-113, RM-11104. Adopted May 25, 2007. Released Jun. 1, 2007. ("2007 mmW NPRM"). Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-07-104A1.pdf; Federal Communications Commission (2013). "Revision of the Commission's Rules Regarding Operation in the 57-64 GHz Band." Report and Order in ET Docket No. 07-113, RM-11104. Adopted Aug. 09, 2013. Released Aug. 09, 2013. ("2013 mmW Report and Order"). Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-13-112A1_Rcd.pdf.

[213] 2013 mmW Report and Order at ¶ 1.

[214] 2016 Spectrum Frontiers R&O and FNPRM at ¶¶ 4, 125-131.

[215] Federal Communications Commission (2003). "Allocations and Service Rules for the 71-76 GHz, 81-86 GHz and 92-95 GHz Bands." Report and Order in WT Docket No. 02-146, RM-10288. Adopted Oct. 16, 2003. Released Nov. 4, 2003. ("2003 mmW Report and Order"). At ¶¶ 1, 2 Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-03-248A1.pdf.

[216] Ibid ¶ 2.

[217] Ibid.

rules established for the 60 GHz band.[218] Various technical rules established for the 70/80/90 GHz bands were subsequently modified in 2005.[219]

The licensing process established by the 2003 mmW Report and Order operates as follows. Applicants who are approved in accordance with FCC Form 601[220] and Commission rules are granted a single, non-exclusive nationwide license.[221] Licenses serve as a prerequisite for registering individual links.[222] This licensing process was decided on based on the need to share these bands with other services including Federal Government systems as well as because systems proposed for these bands concentrate radiated power in a very narrow path and have considerable attenuation at much shorter distances than occurs in the lower microwave bands so that many operations can co-exist in the same vicinity without causing interference to one another.[223]

Initially, coordination of non-Federal Government links with Federal Government operations was accomplished under an existing coordination process; that is, requested non-Federal Government links were recorded in the FCC's Universal Licensing System and coordinated with NTIA through the Interdepartment Radio Advisory Committee (IRAC) Frequency Assignment Subcommittee.[224] In February 2005, this process was replaced by a permanent process where third-party database managers are responsible for recording each proposed non-Federal link in the third-party database link system and coordinating with NTIA's automated "green light/yellow light" mechanism to determine potential for harmful interference with Federal operations.[225] A "green light" response indicates that the link is coordinated with the Federal Government; a "yellow light" response indicates a potential for interference to Federal Government or certain other operations.[226]

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[218] Ibid.
[219] Federal Communications Commission (2005). "Allocations and Service Rules for the 71-76 GHz, 81-86 GHz and 92-95 GHz Bands." Memorandum Opinion and Order in WT Docket No. 02-146. Adopted Feb. 24, 2005. Released Mar. 3, 2005. ("2005 mmW Opinion and Order"). Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-05-45A1.pdf.
[220] Federal Communications Commission. Forms. www.fcc.gov. Available at https://www.fcc.gov/licensing-databases/forms.
[221] 2003 mmW Report and Order ¶ 46. There would be no limit to the number of non-exclusive nationwide licenses that could be granted for these bands.
[222] Ibid.
[223] Ibid ¶ 45.
[224] 2005 mmW Opinion and Order ¶ 3, n. 12.
[225] Ibid; Federal Communications Commission (2005). "Wireless Telecommunications Bureau Announces Permanent Process for Registering Links in the 71-76 GHz, 81-86 GHz, and 92-95 GHz Bands." Public Notice in DA 05-311. Released Feb. 3, 2005. ("2005 mmW Public Notice"). Available at https://apps.fcc.gov/edocs_public/attachmatch/DA-05-311A1.pdf; Federal Communications Commission. Link Registration. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=licensing_4&id=millimeter_wave; Federal Communications Commission. Link Registration. Third Party Database Managers. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=licensing_5&id=millimeter_wave.
[226] Ibid.

As of June 10, 2016, there were 446 active non-exclusive nationwide licenses covering the 70/80/90 GHz bands.[227] Moreover, based upon information available from the third-party database managers that are responsible for registering links in those bands, as of June 10, 2016, there were approximately 22,600 registered fixed links in the 71-76 GHz and 81-86 GHz bands.[228]

As mentioned earlier, the FCC in 2003 determined that it would regulate the 70/80/90 GHz bands under its Part 15 and 101 Rules. The Part 15 rules applicable to the 90 GHz band have been described in the previous subsection concerning the 60 GHz band. Likewise, the general rules contained in 47 C.F.R., Part 101 are laid out in Section 2.3 discussing fixed microwave services. However, additional specific rules applicable to the 70/80/90 GHz bands are laid out in Part 101, Subpart Q.

Service Rules (Part 101, Subpart Q): Many of the sections in this subpart have already been described above, including §101.1501, which stipulates that licenses will be non-exclusive and nationwide, and §101.1523 elaborating on the procedure for sharing and coordination among non-government licensees and between non-government and government services. In addition, among other things, the subpart states that the license term is ten years[229] and requires coordination along the U.S./Canada and U.S./Mexico borders.[230]

Discussion:

We focused our interviews concerning mmW spectrum on a case study of efforts by the City of Santa Cruz, CA to implement mmW based broadband service to government buildings, CAIs, and affordable housing multiple dwelling units as a means to both supplement and substitute for existing wireline based coverage. As part of this case study, we spoke with among others, Boris Maysel, Director of Business Development at Siklu (phone interview on Jul. 26, 2016), which develops and builds mmW radios.[231] We also interviewed Chris Frost and James Hackett, respectively the Director of Technology and Infrastructure and the Director of Business Operations & Development at Cruzio Internet, an Internet Service Provider (ISP) and Competitive Local Exchange Carrier (CLEC) that has for the past three years deployed mmW 60 GHz and 80 GHz band service (phone interview on Aug. 17, 2016).[232] In addition, we note that MapleNet Wireless, mentioned in Section 2.3, relies on the 80 GHz band to offer what are typically approximately one-mile long, "short-haul" point-to-point connections that generally provide 1 Gbps bandwidth.[233]

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[227] 2016 Spectrum Frontiers R&O and FNPRM at ¶ 425.
[228] Ibid.
[229] §101.1513.
[230] §101.1527.
[231] The company website is http://www.siklu.com/.
[232] The company website is http://cruzio.com/.
[233] In particular, MapleNet relies on Siklu's Etherhaul 1200 product. MapleNet Wireless. Siklu. www.maplenetwireless.com. Available at http://www.maplenetwireless.com/products/siklu.

Siklu, which retails various street-level and rooftop devices that can provide maximum throughput varying between 200 Mbps and 2 Gbps (depending on the radio),[234] distinguishes between its V-Band (60 GHz) and E-Band (70/80 GHz) as follows. With V-Band devices, users can expect connections of up to 1,600-2,200 feet with gigabit capacities.[235] The V-Band is touted as supporting the development of palm sized radios and permitting link installation without any coordination or license fees.[236] Siklu devices rely on the equipment's "dynamic interference avoidance algorithms" to mitigate and tolerate interference. In contrast, E-Band devices can achieve longer distances using a larger antenna that provides greater range; interviewees at Cruzio characterized V-Band antennas as being 7 sq in, in contrast to 1-foot E-Band antennas. E-Band licensees pay $75 for a 10-year license and when two links in the same location interfere with one another, the link that was installed first is protected, whereas the second link is reconfigured or removed to prevent interference.[237]

mmW point-to-point connections require line-of-sight signals that, depending on the specific frequency range, can be hampered by rain fade and/or oxygen absorption. However, as Boris Maysel noted during our discussion regarding the E-Band, whereas connectivity is highly attenuated by heavy rain, it is not impacted by fog, humidity, or snow. Siklu bases the reliability of its equipment on rain models from the International Telecommunication Union (ITU), which calculates path loss for different global regions.[238]

Finally, because of their relatively narrow Fresnel zones, mmW are considered relatively secure—that is, because mmW based systems transmit very narrow beams, an individual attempting a security breach would likely need to block the signal in order to intercept traffic, something that would be detected by network users and administrators. In contrast, lower frequencies with larger Fresnel zones could allow for easier interception because data could potentially be intercepted with fewer dropped packets. As a result, for mmW technology, the most vulnerable component is the actual endpoint equipment rather than the wireless transmission path between the endpoints.

2.5. Other Spectrum Bands

Although we have thus far undertaken a thorough examination of bands that we believe are currently most relevant to potential last-mile extensions of backbone and middle mile fiber networks, our analysis is far from exhaustive. We devote the remainder of Section 2 to an overview of other bands currently being used for or likely to be capable of facilitating wireless broadband for underserved communities.

Mobile Wireless Spectrum:

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[234] Siklu. Products. Siklu's Wireless Connectivity Radios. www.siklu.com Available at http://www.siklu.com/products/.
[235] Siklu. E-band vs. V-band—Batman or Invisible Man, you choose. www.siklu.com. Available at http://www.siklu.com/e-band-vs-v-band/.
[236] Ibid.
[237] Ibid. We note that the $75 price quoted by Siklu is at odds with the fee reported in Table 3.
[238] See International Telecommunication Union at http://www.itu.int/en/Pages/default.aspx.

As of the end of 2015, the FCC considered 580.5 megahertz of spectrum (including 89 megahertz of EBS) suitable and available for the provision of mobile telephony/broadband services.[239] This spectrum consists of spectrum described in Table 1.

Table 1: Mobile Wireless Spectrum in FCC Spectrum Screen

Spectrum Band	Megahertz	Band Description
700 MHz	70	698-757, 776-787
Cellular	50	824-849, 869-894
Specialized Mobile Radio (SMR)	14	817-824, 862-869
Personal Communications Service (PCS)	130	1850-1915, 1930-1995
Advanced Wireless Services (AWS)-1	90	1710-1755, 2110-2155
AWS H-Block	10	1915-1920, 1995-2000
AWS-4	40	2000-2020, 2180-2200
Wireless Communications Service (WCS)	20[240]	2305-2320, 2345-2360
Broadband Radio Service (BRS)	67.5[241]	2496-2502, 2602-2614, 2618-2673.5
Educational Broadband Service (EBS)	89[242]	2502-2568, 2572-2602, 2673.5-2690
Total	**580.5**	

The various bands that comprise the mobile wireless spectrum are described in detail in the FCC's annual Mobile Wireless Competition Report.[243] As is the case for BRS and EBS, service rules for the 700 MHz, AWS, and WCS bands are set out in 47 C.F.R., Part 27.[244] Rules for the Cellular band are set out in 47 C.F.R. Part 22, rules for SMR

[239] Eighteenth Mobile Wireless Competition Report at Table IV.A.1.

[240] Only 20 megahertz out of a total of 30 megahertz are included in the spectrum screen, which excludes 10 megahertz presently designated for fixed, rather than mobile broadband. Specifically, the WCS C (2317.5-2320 MHz) and D (2345-2347.5 MHz) blocks are not included in the FCC's spectrum screen. See Federal Communications Commission (2012). "Applications of AT&T Mobility Spectrum LLC, New Cingular Wireless PCS, LLC, Next Wave Wireless, Inc. and San Diego Gas & Electric Company For Consent to Assign and Transfer Licenses." Memorandum Opinion and Order in WT Docket No. 12-240. Adopted Dec. 18, 2012. Released Dec. 18, 2012. At ¶ 31. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-12-156A1_Rcd.pdf.

[241] Only 67.5 megahertz out of a total of 73.5 megahertz are included in the spectrum screen, which excludes BRS Channel 1 (2496-2502 MHz). See 2014 Mobile Spectrum Holdings Report and Order at ¶¶ 118-121.

[242] Only 89 megahertz out of a total of 112.5 megahertz are included in the spectrum screen to account for educational use restrictions as well as the fact that portions of the EBS spectrum are not licensed. See 2014 Mobile Spectrum Holdings Report and Order at ¶¶ 122-125.

[243] See for instance, the most recent, Eighteenth Mobile Wireless Competition Report as well as Appendix A (which is now slightly outdated for certain bands) in the Sixteenth Mobile Wireless Competition Report.

[244] See §27.1; Federal Communications Commission. Advanced Wireless Services (AWS). https://www.fcc.gov/general/advanced-wireless-services-aws; Federal Communications

are set out in C.F.R. Part 90, and rules for PCS are set out in 47 C.F.R. Part 24.[245] The FCC has generally adopted "flexible use" policies in these spectrum bands, allowing licensees to decide which services to offer and what technologies to deploy on.[246]

Since 1994, the FCC has allocated new spectrum in these bands via auctions that are open to any eligible entity that submits an application and upfront payment and is found to be a qualified bidder by the FCC.[247] The FCC's auction website provides detailed information regarding completed, ongoing, and planned auctions.[248] Subject to the FCC's approval, licensees may assign and exchange licenses, in whole or in part (through partitioning and/or disaggregation), on the secondary market.[249] As is the case for EBS licenses described above, licenses are exclusive over a defined geographic area. However, in contrast to EBS licenses, where the license comprised a circle having a 35 mile radius and centered at the station's reference coordinates, for most (though not all) mobile wireless bands, licenses have a predefined area such as a Cellular Market Area, Major Trading Area, or Major Economic Area, many of which are comprised of one or more counties as defined by the U.S. Census Bureau.[250]

By and large, the majority of mobile wireless licenses that have been made available through the primary markets (e.g., auctions), are held by major mobile wireless service providers. As can be observed from Table IV.A.2. in the FCC's Eighteenth Mobile Wireless Competition Report, the largest five mobile wireless service providers together with Dish Network Corporation presently account for 90 percent or more of spectrum holdings on a MHz per individual in the U.S. population (MHz-POPs) basis in every mobile wireless band except for BRS and EBS.

Because many of the licenses held by mobile wireless service providers have been used for mobile wireless deployment, they may not be available on the secondary markets for use by entities such as research and education networks or community anchor institutions hoping to extend their wireline footprint. Moreover, if we use average auction prices as a gauge of the cost of acquiring these licenses we find that the cost

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Commission. Wireless Communications Service (WCS). www.fcc.gov. Available at https://www.fcc.gov/general/wireless-communications-service-wcs.

[245] Federal Communications Commission. Cellular Service. www.fcc.gov. Available at https://www.fcc.gov/general/cellular-service; Federal Communications Commission. Specialized Mobile Radio Service. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=service_home&id=smrs; Federal Communications Commission. Broadband Personal Communications Service (PCS). www.fcc.gov. Available at https://www.fcc.gov/general/broadband-personal-communications-service-pcs.

[246] Eighteenth Mobile Wireless Competition Report at ¶ 49.

[247] Ibid at ¶ 50.

[248] Ibid; Federal Communications Commission. Auctions. www.fcc.gov. Available at http://wireless.fcc.gov/auctions/default.htm?job=auctions_home.

[249] Eighteenth Mobile Wireless Competition Report at ¶ 53. Disaggregation is the division of spectrum into smaller amounts of bandwidth. Partitioning is the division of the license into smaller geographic areas.

[250] See generally, Sixteenth Mobile Wireless Competition Report, Appendix A; United States Census Bureau. www.census.gov. Available at https://www.census.gov/geo/maps-data/maps/stcou_outline.html.

may be prohibitive to smaller applicants or non-profit institutions. For instance, in the 2008 auction of 700 MHz spectrum, the average price for the 700 MHz spectrum was $1.28 per MHz-POP and in the more recent 2015 auction of AWS-3 spectrum (not yet included in the FCC's spectrum screen), the price per MHz-POP was $2.71.[251] To put this into perspective, using the AWS-3 average, this would imply a licensing cost of $271,000 to serve an area of 10,000 individuals with a 10 megahertz bandwidth license.

Citizens Broadband Radio Service:

In April 2015, the FCC established a new Citizens Broadband Radio Service for shared wireless broadband use of the 3550-3700 MHz band (3.5 GHz Band).[252] Rules governing this band are found in 47 C.F.R. Part 96.[253] The Citizens Broadband Radio Service is governed by a three-tiered spectrum authorization framework to accommodate a variety of commercial uses on a shared basis with incumbent federal and non-federal users of the band.[254] Access and operations will be managed by a dynamic Spectrum Access System (SAS), conceptually similar to the databases used to manage Television White Spaces devices.[255]

Previously, the 3550-3650 MHz band had been allocated for use by military radar systems as well as other federal and non-federal uses on a primary or secondary basis, whereby secondary users are not to interfere with primary ones.[256] Similarly, the 3650-3700 MHz band had been allocated for primary use by the federal Radiolocation Service (RLS) at three designated sites as well as for use by ship stations located at least 44 nautical miles from shore in offshore ocean areas on a non-inteference-basis.[257] The 3650-3700 MHz band is also allocated for terrestrial non-federal (fixed wireless) use through non-exclusive nationwide licenses that require the registration of individual fixed and base stations.[258]

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[251] Sixteenth Mobile Wireless Competition Report at ¶ 125; Eighteenth Mobile Wireless Competition Report at ¶ 50.
[252] Federal Communications Commission. 3.5 GHz Band / Citizens Broadband Radio Service. www.fcc.gov. Available at https://www.fcc.gov/rulemaking/12-354.
[253] U.S. Government Code of Federal Regulations. Electronic Code of Federal Regulations. www.ecfr.gov. Available at http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=2dd346ae3b51f2866ab6fb907e755526&mc=true&r=PART&n=pt47.5.96.
[254] Federal Communications Commission. 3.5 GHz Band / Citizens Broadband Radio Service. www.fcc.gov. Available at https://www.fcc.gov/rulemaking/12-354.
[255] Ibid.
[256] Federal Communications Commission (2015). "Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band." Report and Order and Second Further Notice of Proposed Rulemaking in GN Docket No. 12-354. Adopted Apr. 17, 2015. Released Apr. 21, 2015. ("2015 Citizens Broadband R&O and NPRM") At ¶¶ 12, 15-18. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-47A1.pdf.
[257] Ibid at ¶ 20.
[258] Ibid at ¶ 19. Stations operating in this band must employ a contention-based protocol that allows multiple users to share the same spectrum by defining the events that must occur when two or more transmitters attempt to simultaneously access the same channel and establishing rules by which a transmitter provides reasonable opportunities for other transmitters to operate. Stations are also subject to strict power and emissions limits, with limits for mobile and portable

The tiers established for the new Citizens Broadband Radio Service framework are Incumbent Access, Priority Access, and General Authorized Access (GAA). Incumbent users receive interference protection from Citizens Broadband Radio Service users, which consist of Priority and General Authorized Access.[259] Priority Access operations receive protection from GAA operations.[260] Priority Access Licenses (PALs), defined as an authorization to use a 10 megahertz channel in a single census tract for three years, will be assigned in up to 70 megahertz of the 3550-3650 MHz portion of the band.[261] PALs will be authorized to hold no more than 40 megahertz out of the 70 megahertz per census tract at one time.[262] Additionally, PALs will be assigned by competitive bidding.[263] GAA use will be allowed, by rule, throughout the 150 megahertz band, without interference protection from other users of the band.[264]

The effectiveness of the Citizens Broadband Radio Service depends largely on the development and implementation of one or more robust SASs to coordinate use of the 3.5 GHz Band.[265] In 2015, the FCC also noted that the use of an Environmental Sensing Capability (ESC), a system that detects and communicates the presence of a signal from an Incumbent User to a SAS to facilitate shared spectrum access, would allow for more efficient and widespread commercial use of the spectrum while ensuring that federal use of the band is protected.[266] Beginning January 15, 2016, the FCC began accepting proposals for SAS Administrator and ESC Operator applications.[267]

In May 2016, the FCC finalized rules governing the Citizens Broadband Radio Service.[268] This included increasing power levels for certain Citizens Broadband Radio Service Devices (CBSDs) as well as other technical modifications.[269] Among these, the

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stations set substantially below those for base and fixed stations. See also 47 C.F.R., Part 90, Subpart Z. Available at http://www.ecfr.gov/cgi-bin/text-idx?SID=1b762018d73490a1fec7b5980f08c087&mc=true&node=sp47.5.90.z&rgn=div6.

[259] 2015 Citizens Broadband R&O and NPRM at ¶ 4.

[260] Ibid.

[261] Ibid.

[262] Ibid at ¶ 117.

[263] Ibid at ¶ 122.

[264] Ibid at ¶¶ 4, 155. In a license-by-rule regime, individual licenses are not required for GAA spectrum use as long as operators of Citizens Broadband Radio Service Devices (CBSDs) subject to the GAA tier comply with the rules (i.e., non-interference with higher tiers and technical rules) for that tier.

[265] Ibid 301.

[266] Ibid 382.

[267] Federal Communications Commission (2015). “Wireless Telecommunications Bureau and Office of Engineering and Technology Establish Procedure and Deadlines for Filing Spectrum Access System (SAS) Administrator(s) and Environmental Sensing Capability (ESC) Operator(s) Applications.” Public Notice in GN Docket No. 15-319. Released Dec. 16, 2015. Available at https://apps.fcc.gov/edocs_public/attachmatch/DA-15-1426A1_Rcd.pdf.

[268] Federal Communications Commission (2016). “Amendment of the Commission’s Rules with Regard to Commercial Operations in the 3550-3650 MHz Band.” Order on Reconsideration and Second Report and Order in GN Docket No. 12-354. Adopted Apr. 28, 2016. Released May 2, 2016. (“2016 Citizens Broadband Order on Recon. And R&O”). Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-16-55A1.pdf.

[269] Ibid at ¶ 5.

FCC established a definition of use that would allow Priority Access Licensees to certify the extent of their service area to a SAS, while also establishing a maximum point at which they will receive protection from GAA operations.[270]

Although the FCC has now finalized the rules for the Citizens Broadband Radio Service, at the time of writing of this report, the PALs had not yet been auctioned and the FCC had not approved a SAS database administrator or an ESC system. As such, there may be a number of years before the service is widely used for wireless broadband.[271]

Wi-Fi:

As discussed previously, 47 C.F.R., 15 permits the operation of radio frequency devices without issuing individual licenses to operators of these devices. The primary operating condition for unlicensed devices is that the operator must accept whatever interference is received and must not cause harmful interference.[272] The bands typically associated with Wi-Fi are 902-928 MHz (900 MHz Wi-Fi), 2.4-2.4835 GHz (2.4 GHz Wi-Fi), and a large part of the 5 GHz Band.

In particular, in 1997, the FCC amended its Part 15 rules by making available 300 megahertz of spectrum at 5.15-5.35 GHz and 5.725-5.825 GHz for use by unlicensed intentional radiators (U-NII devices), substantially increasing the amount of spectrum available for such devices.[273] In 2003, the FCC made an additional 255 megahertz of spectrum available for U-NII devices at 5.47-5.725 GHz, aligning the frequency bands used by U-NII devices in the U.S. with the frequency bands used by such devices in other parts of the world, thus decreasing development and manufacturing costs for these devices.[274] Finally, in 2014, among other things, the FCC extended the upper edge of the 5.725-5.825 GHz band to 5.85 GHz and removed the indoor-only restriction and increased the permitted power for U-NII devices in the 5.15-5.25 GHz band.[275] Thus, the current 5 GHz band consists of 580 megahertz of spectrum.

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[270] Ibid at ¶ 8.

[271] Stefani, L. (2016, May 6). "The Citizens Broadband Radio Service Proceeding Advances – But When Will The Service Be Up and Running?" Unlicensed Operations and Emerging Technologies in CommLawBlog. Fletcher, Heald, & Hildreth, The Law of Communications. Available at http://www.commlawblog.com/2016/05/articles/unlicensed-operations-and-emerging-technologies/the-citizens-broadband-radio-service-proceeding-advances-but-when-will-the-service-be-up-and-running/.

[272] Federal Communications Commission (2014). "Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band." First Report and Order in ET Docket No. 13-49. Adopted Mar. 31, 2014. Released Apr. 1, 2014. ("2014 5 GHz Report and Order") at ¶ 3. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-14-30A1.pdf.

[273] Federal Communications Commission (1997). "Amendment of the Commission's Rules to Provide for Operation of Unlicensed NII Devices in the 5 GHz Frequency Range." Report and Order in ET Docket No. 96-102, RM-8648, RM-8653. Adopted Jan. 9, 1997. Released Jan. 9, 1997. Available at https://ecfsapi.fcc.gov/file/1757040001.pdf, https://ecfsapi.fcc.gov/file/1757040002.pdf, https://ecfsapi.fcc.gov/file/1757040003.pdf.

[274] 2014 5 GHz Report and Order at ¶ 4.

[275] Ibid at ¶ 2.

Although given its higher frequency most of the Wi-Fi spectrum does not have the propagation and penetration capabilities of the substantially lower TVWS spectrum discussed above, because there is more than half a gigahertz of this spectrum available, it could potentially be used to serve more urban areas. This is evidenced, for instance, by Red Hook Wi-Fi, which partnered with Brooklyn Fiber and the Open Technology Institute (OTI) to set up a "wireless mesh network" throughout Red Hook, Brooklyn to provide free Wi-Fi service in a low income community.[276]

The Open Technology Institute, part of New America, a think tank and civic enterprise "committed to renewing American politics, prosperity, and purpose in the Digital Age," has written that the wide, contiguous channels in the 5 GHz band may be used for gigabit network capacity.[277] Moreover, the FCC is considering potential sharing of other bands in the 5 GHz band with U-NII devices that may further expand the bandwidth available for Wi-Fi. For example, in June 2016, the FCC sought to update and refresh the record on the status of potential sharing solution between U-NII devices and Decidated Short Range Communications (DSRC) operations in the 5.850-5.925 GHz band, which is currently designed to facilitate information transfer between appropriately equipped vehicles and infrastructure systems (V2I) and between other vehicles (V2V).[278] Five parties, including Cisco and Qualcomm, submitted prototype U-NII devices, which are now in the process of being tested by the FCC for potential sharing solutions.[279]

Spectrum Frontiers:

Whereas Section 2.4 discussing millimeter wave spectrum focused on regulation of certain mmW bands viewed as appropriate for point-to-point communication, the 2016 Spectrum Frontier R&O and FNPRM envisioned that mmW spectrum could be used for mobile wireless service as well. The actions that the FCC took in the Spectrum Frontier Report and Order include the following:[280]

- Creating upper microwave flexible use, geographic area licenses authorizing mobile operations in the 27.5-28.35 GHz (or 28 GHz) and 38.6-40 GHz (or 39 GHz) bands.

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[276] 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/.

[277] Calabrese, M.A. (2016, Jan.). "Spectrum Silos to Gigabit Wi-Fi: Sharing the 5.9 GHz 'Car Band.'" Open Technology Institute, New America. Available at https://static.newamerica.org/attachments/12279-spectrum-silos-to-gigabit-wi-fi/OTI_5.9ghz_web.5de7495517f3416cae27fe811f0f985b.pdf.

[278] Federal Communications Commission (2016). "The Commission Seeks to Update and Refresh the Record in the 'Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band' Proceeding." Public Notice in ET Docket No. 13-49. Released Jun. 1, 2016. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-16-68A1.pdf.

[279] Federal Communications Commission (2016). "Office of Engineering and Technology Announces Schedule for Testing Prototype U-NII-4 Devices." Public Notice in ET Docket No. 13-49. Released Oct. 7, 2016. Available at http://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db1007/DA-16-1054A1.pdf.

[280] 2016 Spectrum Frontiers R&O and FNPRM at ¶ 4.

- Adopting a band plan that allows for continuity of commercial operations between the 37-38.6 GHz (or 37 GHz) band and the 39 GHz band, subject to protection for a limited number of Federal military sites.
- Granting mobile operating rights to existing Local Multipoint Distribution Service and 39 GHz band licenses.[281]
- Adopting spectrum holdings policies for the 28 GHz, 37 GHz, and 39 GHz bands that will apply to licenses acquired through auctions and the secondary market.
- Requiring licensees to submit a statement describing its security plans and related information prior to commencing operations.

In addition, in the Spectrum Frontiers Further Notice of Proposed Rulemaking (FNPRM), the FCC proposed rules that include the following:[282]

- Seeking comment on authorizing fixed and mobile use of the following bands: 24.25-24.45 GHz together with 24.75-25.25 GHz (24 GHz band), 31.8-33 GHz (32 GHz band), 42-42.5 GHz (42 GHz band), the 47.2-50.2 GHz (47 GHz band), 50.4-52.6 GHz (50 GHz band), and the 71-76 GHz band together with the 81-86 GHz bands (70/80 GHz bands).
- Seeking comment on establishing performance requirements for innovative uses associated with the Internet of Things (IoT) such as machine-to-machine communications, healthcare devices, autonomous driving cars, and home and office automation.

It is worth noting that licensing for many of the bands discussed by the 2016 Spectrum Frontiers R&O and FNPRM deviates substantially from that in the 60 GHz or 70/80/90 GHz bands. For instance, in 2000, the FCC assigned the 24 GHz band (at the time, consisting of 24.25-24.45 GHz and 25.05-25.25 GHz spectrum) for licensing throughout the U.S. by Economic Areas (EAs) consisting of 172 service areas with ten-year license terms from the date of grant.[283] In 2004, the FCC held Auction 56, in which it made 890 24 GHz licenses available. However, only seven licenses were sold and five of those licenses are currently active.[284] Similarly, the 39 GHz band is licensed by EA and consists of 14 blocks of 50 by 50 megahertz channels.[285] Out of the 2,464 possible terrestrial fixed service EA licenses available in this band, only 870 licenses currently exist.[286]

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[281] See Federal Communications Commission. Local Multipoint Distribution Service. www.fcc.gov. Available at http://wireless.fcc.gov/services/index.htm?job=service_home&id=lmds.
[282] 2016 Spectrum Frontiers R&O and FNPRM at ¶ 5.
[283] Federal Communications Commission (2000). "Amendments to Parts 1, 2, 87, and 101 of the Commission's Rules to License Fixed Services at 24 GHz." Report and Order in WT Docket No. 99-327. Adopted Jul. 25, 2000. Released Aug. 1, 2000. ("2000 24 GHz Report and Order.") at ¶ 2. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-00-272A1.pdf.
[284] 2016 Spectrum Frontiers R&O and FNPRM at ¶ 379. In addition, FiberTower holds a total of 38 pre-auction Digital Electronic Messaging Service licenses in this band.
[285] Ibid at ¶ 74.
[286] Ibid.

In both cases, the licenses resemble more closely the type of exclusive geographic licensing observed in the mobile wireless spectrum bands than in other bands, such as the fixed microwave and mmW bands discussed above that are used for point-to-point and point-to-multipoint deployment. Presently, FiberTower, one of the licensees of spectrum in both the 24 GHz and 39 GHz bands offers access to its holdings of these bands through its spectrum leasing programs.[287] It also offers equipment along with a spectrum lease to enable customers to install their own broadband links.

[287] FiberTower. Our Services. www.fibertower.com. Available at http://www.fibertower.com/spectrumservices/. A list of FiberTower markets is available at https://static1.squarespace.com/static/53ad732ee4b06e52f1ceda08/t/5730f776cf80a12bea518953/1462826875996/List+of+Markets+for+Website.pdf.

3. OTHER WIRELESS INTERNET BROADBAND REGULATIONS

Although in Section 2, we have expounded at length regarding the rules that apply to various spectrum bands, there are other regulations, besides those pertaining to spectrum that apply to wireless Internet service more generally. For instance, as we had mentioned previously, the FCC's Competition & Infrastructure Policy Division (CIPD) develops infrastructure policies that wireless licensees must follow in order to be able to offer service. These include taking appropriate measures to protect environmental and historic resources, as required by the National Environmental Policy Act (NEPA) and the National Historic Preservation Act (NHPA). Other regulations include those implemented at the state and local level, rather than at the Federal level, particularly with regard to zoning and land use.

3.1. Tower and Antenna Siting

Title 47 C.F.R., Part 1, Subpart I implements the FCC's rules for environmental review, ensuring that licensees and registrants take appropriate measures to protect environmental and historic resources.[288] On its website, the FCC provides a thorough overview of its tower and antenna siting policies, including compliance with environmental statutes such as NEPA and NHPA.[289] Here, we briefly specify the most relevant policies and encourage the reader to access the FCC for more detail. As the FCC website notes, a new tower construction requires:

- Approval from state or local governing authorities.
- Compliance with FCC rules implementing NEPA,[290] including separate procedures for NHPA[291] and the Endangered Species Act.[292]

Depending on the tower's height and location, construction may also require:

- Federal Aviation Administration (FAA) notification.[293]

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[288] 47 C.F.R., Part 1, Subpart I, Procedures Implementing the National Environmental Policy Act of 1969. Available at http://www.ecfr.gov/cgi-bin/text-idx?SID=4d39e24d7ad053a8ddd87f7ac22c06e2&mc=true&node=sp47.1.1.i&rgn=div6.

[289] Federal Communications Commission. Tower and Antenna Siting. www.fcc.gov. Available at https://www.fcc.gov/general/tower-and-antenna-siting.

[290] In particular, §1.1307 stipulates situations that require an Environmental Assessment, such as, for instance, if the tower construction takes place in an officially designated wilderness area or wildlife preserve.

[291] §1.1307(4)(i) states that an Environmental Assessment is required for facilities that may affect districts, sites, buildings, structures or objects, significant in American history, architecture, archeology, engineering or culture

[292] §1.1307(3) states that an Environmental Assessment is required for facilities that (i) may affect listed threatened or endangered species or designated critical habitats; or (ii) are likely to jeopardize the continued existence of any proposed endangered or threatened species or likely to result in the destruction or adverse modification of proposed critical habitats.

[293] Title 14 C.F.R., Part 77.9 specifies the requirements for filing with the Federal Aviation Administration (FAA). These requirements vary based on factors such as height, proximity to an

- Antenna Structure Registration (ASR) with the FCC.[294]

Section 332(c)(7) of the Communications Act preserves general local zoning authority of state and local governments subject to certain limitations.[295] In particular, state and local governments are not permitted to unreasonably discriminate among providers of functionally equivalent services seeking to place, construct, or modify personal wireless service facilities or to regulate these activities in a way that would prohibit the provision of wireless services.[296] Among other things, Section 332(c)(7) also requires state and local governments to act on requests for site authorizations within a reasonable period of time.[297]

NEPA requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions.[298] Environmental review under NEPA can involve three different levels of analysis:[299]

- Categorical Exclusion (CATEX): actions which do not individually or cumulatively have a significant effect on the human environment and for which, therefore, neither an environmental assessment nor an environmental impact statement is required.[300]
- Environmental Assessment/Finding of No Significant Impact: a document briefly presenting the reasons why an action that is not categorically excluded will not have a significant effect on the human environment and for which an environmental impact statement therefore will not be prepared.[301]

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airport, location, and frequencies emitted from the structure. Federal Aviation Administration. Notice Criteria Tool. www.faa.gov. Available at https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showNoNoticeRequiredToolForm; 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?rgn=div5&node=14:2.0.1.2.9.

[294] An antenna structure must be registered if the antenna structure is taller than 200 feet above ground level or may interfere with the flight path of a nearby airport. Federal Communications Commission. Antenna Structure Registration (ASR) – Help. www.fcc.gov. Available at https://www.fcc.gov/help/antenna-structure-registration-asr-help. 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=d1dca0f38d050fc2925ab8f5668e5745&mc=true&node=pt47.1.17&rgn=div5.

[295] 47 U.S.C. §332(c)(7). Available at https://www.law.cornell.edu/uscode/text/47/332.

[296] §332(c)(7)(B)(i).

[297] §332(c)(7)(B)(ii).

[298] U.S. Environmental Protection Agency. What is the National Environmental Policy Act? www.epa.gov. Available at https://www.epa.gov/nepa/what-national-environmental-policy-act.

[299] U.S. Environmental Protection Agency. National Environmental Policy Act Review Process. www.epa.gov. Available at https://www.epa.gov/nepa/national-environmental-policy-act-review-process.

[300] 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=333e9c1173ecdd17f6b75713a2b8993a&mc=true&node=se40.37.1508_14&rgn=div8.

[301] 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=333e9c1173ecdd17f6b75713a2b8993a&mc=true&node=se40.37.1508_113&rgn=div8.

- Environmental Impact Statements (EIS): a detailed written statement required if an action is determined to significantly affect the quality of the human environment.[302] The regulatory requirements for an EIS are outlined on the website of the U.S. Environmental Protection Agency.[303]

The FCC considers registering and licensing towers and facilities to be actions that trigger agency NEPA obligations.[304] Although compliance with NEPA rests with the FCC, the agency has delegated initial assessment of CATEXs and preparation of environmental assessments to licensees and applicants.[305] Categories of facilities requiring environmental assessments are set out in Part 1, Subpart I, §1.1307 and are summarized in the FCC's tower and antenna siting website (https://www.fcc.gov/general/tower-and-antenna-siting). After an Environmental Assessment is filed, the document is put on public notice for one month, during which the FCC ensures its sufficiency.[306] If no objections or issues are identified, the FCC issues a Finding of No Significant Impact.[307]

Title 14 C.F.R., Part 77 establishes requirements to provide notice to the FAA of certain proposed construction, or the alteration of existing structures.[308] Construction or alterations requiring notice are listed in §77.9, and include for instance towers that are more than 200 feet above ground level at their site.[309] If required to file notice under §77.9, a party must submit to the FAA a completed FAA Form 7460-1, Notice of Proposed Construction or Alteration.[310]

Title 47 C.F.R., Part 17 prescribes certain procedures for antenna structure registration and standards with respect to the Commission's consideration of proposed antenna structures, including potentially to require the painting, and/or illumination of antenna structures if and when in its judgment such structures may constitute a menace to air navigation.[311] Owners of proposed structures who must file with the FAA must also file

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[302] 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=333e9c1173ecdd17f6b75713a2b8993a&mc=true&node=se40.37.1508_111&rgn=div8.
[303] U.S. Environmental Protection Agency. National Environmental Policy Act Review Process. www.epa.gov. Available at https://www.epa.gov/nepa/national-environmental-policy-act-review-process.
[304] Federal Communications Commission. Tower and Antenna Siting. www.fcc.gov. Available at https://www.fcc.gov/general/tower-and-antenna-siting. In particular, 47 C.F.R., Part 1, Subpart I implements Subchapter I of the National Environmental Policy Act of 1969, as amended, Section 42 U.S.C. 4321-4335 (see §1.1301).
[305] Federal Communications Commission. Tower and Antenna Siting. www.fcc.gov. Available at https://www.fcc.gov/general/tower-and-antenna-siting.
[306] Ibid.
[307] Ibid.
[308] 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?rgn=div5&node=14:2.0.1.2.9#sp14.2.77.a. In particular, see 14 C.F.R., §77.1.
[309] 14 C.F.R., §77.9(a).
[310] 14 C.F.R., §77.7(a).
[311] U.S. Government Code of Federal Regulations. Electronic Code of Federal Regulations. www.ecfr.gov. Available at http://www.ecfr.gov/cgi-bin/text-

FCC Form 854 and submit an FAA "no hazard" determination to the FCC.[312] Additional information regarding antenna structure registration is available at the FCC's tower and antenna siting website as well as at its ASR help site (https://www.fcc.gov/help/antenna-structure-registration-asr-help) and its ASR site (http://wireless.fcc.gov/antenna/index.htm?job=home).

3.2. Security Compliance

Health Information Security:

The Office of the National Coordinator for Health Information Technology (ONC) in the U.S. Department of Health and Human Services (HHS) supports the adoption of health information technology and the promotion of nationwide health information exchange to improve health care.[313] ONC is the principal federal entity charged with coordination of nationwide efforts to implement and use the most advanced health information technology and the electronic exchange of health information.[314] The position of National Coordinator was created in 2004, through an Executive Order, and legislatively mandated in the Health Information Technology for Economic and Clinical Health Act (HITECH Act) of 2009.[315] The HITECH Act provides HHS with the authority to establish programs to improve health care quality, safety, and efficiency through the promotion of health IT, including electronic health records and private and secure electronic health information exchange.[316]

Additionally, the Health Insurance Portability and Accountability Act (HIPAA) of 1996, which protects health insurance coverage for workers and their families when they change or lose their jobs, required the establishment of national standards for electronic health care transactions.[317] The HIPAA Security Rule specifies safeguards that must be in place to ensure appropriate protection of electronic protected health information.[318] The Security Rule applies to health plans, health care clearinghouses, and to any health care provider who transmits health information in electronic form in connection with a transaction for which the Secretary of HHS has adopted standards under HIPAA.[319]

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idx?SID=32e5a902576fdf53c0d8697b0d651eff&mc=true&node=pt47.1.17&rgn=div5#se47.1.17_11. In particular, see §17.1(a) and §17.1(b).

[312] §17.4(b).

[313] HealthIT.gov. About ONC. www.healthit.gov. Available at https://www.healthit.gov/newsroom/about-onc.

[314] Ibid.

[315] Ibid. The HITECH Act is embedded in the American Recovery and Reinvestment Act of 2009 (ARRA). The excerpts of the HITECH Act within ARRA are available at https://www.healthit.gov/sites/default/files/hitech_act_excerpt_from_arra_with_index.pdf.

[316] HealthIT.gov. Health IT Legislation and Regulations. www.healthit.gov. Available at https://www.healthit.gov/policy-researchers-implementers/health-it-legislation.

[317] Ibid. See also https://www.gpo.gov/fdsys/pkg/PLAW-104publ191/html/PLAW-104publ191.htm.

[318] HHS.gov. Health Information Privacy. Summary of the HIPAA Security Rule. www.hhs.gov. Available at http://www.hhs.gov/hipaa/for-professionals/security/laws-regulations/index.html.

[319] Ibid.

Crucially, most health care providers and health plans use the services of a variety of other persons or businesses. The HIPAA Privacy Rule allows covered providers and health plans to disclose protected health information to these "business associates" if the providers or plans obtain satisfactory assurances that the business associate will use the information only for the purposes for which it was engaged by the covered entity, will safeguard the information from misuse, and will help the covered entity comply with some of the covered entity's duties under the Privacy Rule.[320]

The Security Rule protects all individually identifiable health information a covered entity creates, receives, maintains or transmits in electronic form, referred to as "electronic protected health information" (e-PHI).[321] Broadly, the Rule requires covered entities to maintain reasonable and appropriate administrative, technical, and physical safeguards for protecting e-PHI, which entails consideration of an entity's technical, hardware, and software infrastructure.[322]

Of particular relevance for this report, a covered entity must implement technical security measures that guard against unauthorized access to e-PHI that is being transmitted over an electronic network.[323] The relevant rule is specified in 45 C.F.R. §164.312(e).[324] Implementation consists of (i) *integrity controls*: security measures to ensure that electronically transmitted electronic protected health information is not improperly modified without detection until disposed of, and (ii) *encryption*: a mechanism to encrypt electronic protected health information whenever deemed appropriate. Notably, integrity controls and encryption are viewed as "addressable," as opposed to "required" implementation specifications, meaning that a covered entity must assess whether each specification is a reasonable and appropriate safeguard in its environment when analyzed with reference to the likely contribution to protecting electronic protected health information.[325]

When speaking to a number of the ISPs and equipment vendors above, we learned that it is standard practice to encrypt wireless data either through software or hardware encryption and that it is generally the responsibility of the organization that transmits the data to certify compliance with the relevant security requirements. In particular, 45 C.F.R. §164.316 requires covered entities to maintain written records (which may be electronic) of the policies and procedures used to comply with security standards for the protection of e-PHI.

Various companies that distribute wireless network components and equipment have written white papers that explain how an organization may attain HIPAA compliance pursuant to its obligations under 45 C.F.R. Part 164. For example, Cisco (Meraki) has

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[320] HHS.gov. Health Information Privacy. Business Associates. www.hhs.gov. Available at http://www.hhs.gov/hipaa/for-professionals/privacy/guidance/business-associates/index.html.
[321] HHS.gov. Health Information Privacy. Summary of the HIPAA Security Rule. www.hhs.gov. Available at http://www.hhs.gov/hipaa/for-professionals/security/laws-regulations/index.html.
[322] Ibid.
[323] Ibid.
[324] 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=6c6a1143a6eac0f32da562dbf0379dc7&mc=true&node=pt45.1.164&rgn=div5.
[325] 45 C.F.R. §164.306(d).

made available a white paper entitled, “HIPAA Compliance for the Wireless LAN,” targeted at healthcare IT administrators who are responsible for the design and implementation of a wireless network.[326] White papers such as this generally specify how equipment provided by the authoring organization can satisfy the technical security requirements in 45 C.F.R. Part 164.

The Payment Card Industry Data Security Standard:

The Payment Card Industry (PCI) Data Security Standard (DSS) is a proprietary set of technical security requirements intended for organizations that handle credit cardholder information.[327] The PCI DSS is promoted by the PCI Security Standards Council, founded by American Express, Discover Financial Services, JCB International, MasterCard, and Visa Inc., which have agreed to incorporate the PCI DSS as part of the technical requirements for each of their data security compliance programs.[328]

The PCI Security Standards Council advocates that the best way to maximize security of cardholder data is to continuously monitor and enforce the use of controls specified in the PCI DSS.[329] Validation of compliance with the PCI Data Security Standard is determined by individual payment brands or acquiring banks.[330] The PCI DSS process involves identifying all system components that are located within or connected to the cardholder data environment.[331] This is referred to as scoping, an annual process that must occur prior to the annual assessment.[332] A Qualified Security Assessor is a data security firm that is qualified by the PCI Council to perform on-site PCI DSS assessments.[333] Entities report their compliance status with the PCI DSS to their respective acquiring financial institutions or payment card brand.[334] Quarterly submission of a report for network scanning may also be required.[335] Specific PCI DSS requirements (as listed by the PCI Council) are:[336]

1. Install and maintain a firewall configuration to protect cardholder data.
2. Do not use vendor-supplied defaults for system passwords and other security parameters.
3. Protect stored cardholder data.

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[326] Cisco (Meraki) (2015, June). “HIPAA Compliance for the Wireless LAN.” White Paper. Available at https://meraki.cisco.com/lib/pdf/meraki_whitepaper_HIPAA.pdf.
[327] PCI Security Standards Council. PCI SSC Data Security Standards Overview. www.pcisecuritystandards.org. Available at https://www.pcisecuritystandards.org/about_us/.
[328] Ibid.
[329] PCI Security Standards Council. How to Secure With the PCI Data Security Standard. www.pcisecuritystandards.org. Available at https://www.pcisecuritystandards.org/pci_security/how.
[330] Ibid.
[331] Ibid.
[332] Ibid.
[333] Ibid. A list of Qualified Security Assessors is available at https://www.pcisecuritystandards.org/assessors_and_solutions/qualified_security_assessors.
[334] Ibid.
[335] Ibid.
[336] PCI Security Standards Council. PCI Security Standards. www.pcisecuritystandards.org. Available at https://www.pcisecuritystandards.org/pci_security/maintaining_payment_security.

4. Encrypt transmission of cardholder data across open, public networks.
5. Use and regularly update anti-virus software or programs.
6. Develop and maintain secure systems and applications.
7. Restrict access to cardholder data by business need-to-know.
8. Assign a unique ID to each person with computer access.
9. Restrict physical access to cardholder data.
10. Track and monitor all access to network resources and cardholder data.
11. Regularly test security systems and processes.
12. Maintain a policy that addresses information security for employees and contractors.

Additional information is available on the PCI Council website at https://www.pcisecuritystandards.org/pci_security/maintaining_payment_security. In particular, note the website's "Document Library." As was the case with HIPAA compliance, various companies that distribute wireless network components have made available white papers that discuss PCI DSS. For instance, Cisco (Meraki) offers a 2011 white paper entitled "PCI v2.0 Compliance for Wireless LAN."[337] However, in 2014, improved attacks such as the Heartbleed bug severely compromised the capability of older encryption technologies. In a more recent set of white papers, Cisco, together with Verizon, addresses vulnerabilities in previous products.[338]

3.3. State Regulation

State level regulations that could impact wireless broadband deployment are generally concerned with infrastructure related regulation (e.g., zoning and land use). An exhaustive overview of all individual state regulations is beyond the scope of this report.[339] Instead, we focus here on state rules and initiatives that specifically pertain to wireless deployment for the Quilt Network (refer to footnote 1) members who have

[337] Cisco (Meraki) (2011, November). "PCI v2.0 Compliance for Wireless LAN." White Paper. Available at https://meraki.cisco.com/lib/pdf/meraki_whitepaper_PCI.pdf.

[338] In particular, Cisco notes that SSL version 3.0 and TLS 1.0 are no longer secure protocols and therefore these protocols can no longer be used after June 30, 2016 for systems that carry or manage credit card information. Cisco (2015). "SSL/TLS 1.0 Vulnerability Response: SAFE Compliance Architecture Guide Supplement." White Paper. Available at http://www.cisco.com/c/dam/en/us/solutions/collateral/enterprise-networks/pci-compliance/vulnerability-response.pdf; Cisco and Verizon (2014). PCI DSS 3.0 Update: A Cisco and Verizon Perspective. White Paper. Available at http://www.cisco.com/c/dam/en/us/solutions/collateral/enterprise-networks/pci-compliance/pci-dss-30-wp.pdf.

[339] There are myriad state and/or local rules that apply to highly specific aspects of wireless telecommunications that we do not explore. As an example, Michigan's Military Personnel Wireless Contract Act (Act 218 of 2010) provides when certain active duty service members can terminate contracts with wireless telecommunications providers. Of particular note, we do not explore regulations involving taxation of wireless services and/or equipment, or state specific prohibitions on use of wireless services while operating a vehicle.

provided support for this report. The states that we explore are Michigan, Missouri, New Jersey, New York, North Carolina, and Wisconsin.[340]

Michigan:

The Michigan Telecommunications Act (Act 179 of 1991) regulates and insures the availability of certain telecommunications services and prescribes powers and duties pertaining to certain agencies and officials.[341] Other relevant statutes include the Michigan Broadband Development Authority Act (Act 49 of 2002), intended to encourage private sector investment in broadband deployment,[342] as well as the Michigan Zoning Enabling Act (Act 110 of 2006), with regard to wireless communications equipment.[343]

Michigan Telecommunications Act: The purpose of the Michigan Telecommunications Act is, among other things,[344]

- To ensure that every person has access to just, reasonable, and affordable basic residential telecommunication service.
- Encourage the introduction of new services, the entry of new providers, the development of new technologies, and increase investment in the telecommunication infrastructure in this state through incentives to providers to offer the most efficient services and products.
- Improve the opportunities for economic development and the delivery of essential services including education and health care.

The Michigan Public Service Commission has the jurisdiction and authority to administer this act and all federal telecommunications laws, rules, orders, and regulations that are delegated to the state.[345]

Michigan is one of the Quilt Network states described in this report that has created certain impediments on public communications initiatives. In particular, with some exceptions, a public entity—county, city, village, township, or any agency or subdivision of the public entity—may provide telecommunication services within its boundaries *only if* it has issued a request for competitive sealed bids to provide telecommunication

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[340] The particular Quilt members providing support are described in Appendix 1.
[341] Michigan Legislature. Michigan Telecommunications Act. http://www.legislature.mi.gov Available at http://www.legislature.mi.gov/(S(402lwzpaquu1hsenujj0ffeg))/mileg.aspx?page=getobject&objectname=mcl-Act-179-of-1991&query=on&highlight=telecommunications.
[342] Michigan Legislature. Michigan Broadband Development Authority Act. http://www.legislature.mi.gov Available at http://www.legislature.mi.gov/(S(402lwzpaquu1hsenujj0ffeg))/mileg.aspx?page=getObject&objectName=mcl-484-3202&highlight=broadband. In particular, see Act 49 of 2002 §484.3202.
[343] Michigan Legislature. Michigan Zoning Enabling Act. http://www.legislature.mi.gov Available at http://www.legislature.mi.gov/(S(402lwzpaquu1hsenujj0ffeg))/mileg.aspx?page=getobject&objectname=mcl-125-3514&query=on&highlight=wireless. In particular, see Act 110 of 2006 §125.3514.
[344] Michigan Act 179 of 1991, §484.2101.
[345] Ibid §484.2201.

services and has received *less than* 3 qualified bids from private providers and it has been more than 60 days from the date the request for bids was issued.[346] Moreover, public entities on their own cannot provide telecommunication services outside their boundaries.[347] An important exemption is for public entities that currently provide telecommunication services.[348]

However, the Michigan Public Service Commission generally does not have authority over among other services, cellular, mobile, or retail broadband services (defined as a retail service capable of transmitting data over an access line at a rate greater than 200 Kbps).[349]

Michigan Broadband Development Authority Act: According to the Michigan Broadband Development Authority Act, the legislature determined that certain areas of Michigan were not being adequately served with broadband services and that it was essential that broadband infrastructure be expanded to provide broadband services.[350] The act was intended to provide a method to assure that economic, technological, and logistical integrated broadband services are provided throughout Michigan on a nondiscriminatory basis.[351] In particular, the Michigan Broadband Development Authority was created to assist in the financing and refinancing of the private and public sectors' development of a statewide broadband infrastructure, possibly through the issuance of bonds and notes, the provision of loans, and formation of joint ventures and partnership arrangements to broadband developers and operators.[352]

Michigan Zoning Enabling Act: The Michigan Zoning Enabling Act states that wireless communications equipment is a permitted use of property and is not subject to special land use approval if a number of requirements are met.[353] For instance, these requirements stipulate that wireless communications equipment will be collocated on an existing wireless communications support structure or in an existing equipment compound, that the existing wireless communications support structure or existing equipment compound is in compliance with the local unit of government's zoning ordinance, and that the proposed collocation will not increase the overall height or width of the support structure beyond certain thresholds.[354]

Missouri:

The two major Missouri statutes that apply to broadband and/or wireless services include the Uniform Wireless Communications Infrastructure Deployment Act (in Chapter 67), intended to encourage and streamline the deployment of broadcast and broadband facilities and to help ensure that robust wireless communication services are

[346] Ibid §484.2252.
[347] Ibid §484.2252(2).
[348] Ibid §484.2252(5)(c).
[349] Ibid §484.2401(1).
[350] Michigan Act 49 of 2002, §484.3202.
[351] Ibid.
[352] Ibid.
[353] Michigan Act 110 of 2006, §125.3514.
[354] Ibid.

available throughout Missouri[355] and Chapter 392, which broadly sets out regulations for telephone and telegraph companies.[356]

Chapter 392: Although Chapter 392 comprises of various rules that apply to telecommunications services, it states that with the exception of interconnected voice over Internet protocol (IP), broadband and other IP-enabled services are not subject to regulations under Chapter 392 or Chapter 386, the "Public Service Commission Law" that creates the Missouri Public Service Commission that regulates various utilities in the State of Missouri.[357]

Notably, like Michigan, Missouri restricts certain public communications initiatives. In particular, Chapter 392 states that no political subdivision of Missouri shall provide or offer for sale, either to the public or to a telecommunications provider, a telecommunications service or telecommunications facility used to provide a telecommunications service, with exceptions for service provided for own use, emergency services, medical or educational purposes, services to students if provided by an educational institution, or Internet-type services.[358]

Chapter 67.5090: The Uniform Wireless Communications Infrastructure Deployment Act stipulates various state limitations with respect to regulating wireless services and also lays out various zoning requirements. Among the limitations, the Act states that no [Missouri] authority shall dictate the type of wireless facilities, infrastructure or technology to be used by an entity seeking to provide such service, or to require an entity to remove existing wireless support structures or wireless facilities, wherever located, as a condition for approval of an application.[359] Additionally, it specifically limits an authority from regulating aspects of wireless service that are already covered by the FCC, FAA, and other Federal agencies.[360]

This act does permit state, county, municipal and other Missouri authorities with jurisdiction over land use, planning, or zoning decisions[361] to continue to exercise that authority with regard to the siting of new wireless support structures or substantial modifications to such structures and lays out the rules governing that authority.[362] In

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[355] Missouri Chapter 67, §67.5090. Missouri General Assembly. Missouri Revised Statutes. http://www.moga.mo.gov. Available at http://www.moga.mo.gov/mostatutes/chapters/chapText067.html.
[356] Missouri General Assembly. Missouri Revised Statutes. http://www.moga.mo.gov. Available at http://www.moga.mo.gov/mostatutes/stathtml/39200002451.html.
[357] Missouri Chapter 392, §392.611; Missouri Chapter 386, Missouri General Assembly. Missouri Revised Statutes. http://www.moga.mo.gov. Available at http://www.moga.mo.gov/mostatutes/chaptersIndex/ChaptIndex386.html.
[358] Missouri Chapter 392, §392.410(7).
[359] Missouri Chapter 67, §67.5094.
[360] Ibid.
[361] In particular, "Authority" is defined as each state, county, and municipal governing body, board, agency, office, or commission authorized by law and acting in its capacity to make legislative, quasi-judicial, or administrative decisions relative to zoning or building permit review of an application. Chapter 67, §67.5092.
[362] Missouri Chapter 67, §67.5096, §67.5098.

particular, this act limits the time allowed for the authority to review an application for new construction or substantial modifications to 120 calendar days.[363]

New Jersey:

New Jersey Titles 40 and 48 are the two major statutes that broadly set out rules that pertain to broadband deployment in the State of New Jersey.[364] In particular, Title 40, which regulates New Jersey municipalities and counties, permits various local authorities to construct, own, and operate broadband telecommunications service via wireless community networks.[365] Title 48 is concerned with public utilities regulation.[366]

Voice Over Internet Freedom Act: New Jersey Title 48 establishes and specifies the authority of the New Jersey Board of Public Utilities, which oversees regulated utilities that provide critical services such as natural gas, electricity, water, telecommunications, and cable television.[367] Title 48, Section 17 sets out regulation pertaining to construction and maintenance of necessary poles, wires, conduits, and other fixtures.[368]

Of particular interest for broadband deployment, Sections 17:32-35, referred to as the "Voice over Internet Freedom Act," state that the proliferation of new technologies and applications and the growth in the number of providers developing and offering innovative services using Internet Protocol are due in large part to a light regulatory touch, including freedom from traditional telephone regulation that these new technologies and services and the companies that offer them have enjoyed in New Jersey.[369] As such, the Act states that neither the State of New Jersey, nor any department, agency, board or commission thereof, nor any political subdivision of the State shall enact, adopt or enforce any law, ordinance, resolution, rule, regulation, order, standard or other provision, either directly or indirectly, having the force and effect of law that regulates, or has the effect of regulating, the rates, terms and conditions of VoIP service or IP-enabled service offered to customers.[370]

Title 40:9D: Section 9D-1 of New Jersey Title 40 permits local units—defined loosely as any county, municipality, special district or various other public bodies established by New Jersey law, but not including school districts—to construct, own or operate broadband telecommunications infrastructure to provide broadband telecommunications service via a wireless community network.[371] Moreover, New Jersey local units may

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[363] Missouri Chapter 67, §67.5096(4), §67.5098(4).
[364] New Jersey State Legislature. New Jersey Permanent Statutes. www.njleg.state.nj.us/. Available at http://lis.njleg.state.nj.us/cgi-bin/om_isapi.dll?clientID=430443326&depth=2&expandheadings=off&headingswithhits=on&infobase=statutes.nfo&softpage=TOC_Frame_Pg42.
[365] New Jersey Title 40, §40:9D.
[366] New Jersey Title 48, §48.
[367] Ibid.
[368] Ibid §48:17.
[369] Ibid §48:17-33(2)(b). Consequently, the Act states that these economic benefits, including consumer choice, new jobs, and significant capital investment, will be jeopardized and competition minimized by the imposition of traditional State entry and rate regulation on Voice over IP and IP-enabled service. Ibid §48:17-33(2)(c).
[370] Ibid §48:17-35.
[371] New Jersey Title 40, §40:9D.

contract with private entities to provide such services and sell capacity and grant similar rights to private entities for the same purpose.[372] However, crucially, local units providing broadband over wireless community networks cannot subsidize these services by offering them below cost.[373]

New York:

Although a number of bills have been proposed in the last few years, to the authors' knowledge, there are relatively few New York State statutes that presently specifically apply to Internet broadband and wireless technology.[374] The New York statutes that relate to broadband and/or telecommunications include the Public Service Laws, Education Laws, and the State Technology Laws.[375]

Public Service Law: The New York Public Service Law establishes and specifies the authority of the Department of Public Service, which regulates utility services, including telecommunications, in New York State.[376] However, although this law applies to telegraph and telephone lines and corporations, broadband regulation is not specifically mentioned.[377] Moreover, Article 5 of the Public Service Law states that a telephone corporation providing non-basic services[378] does not have to provide a tariff schedule for these services to the Department of Public Service and can withdraw the schedule if previously provided.[379]

Education Law: Article 73, Part 4 of the Education Law provides for special apportionments and grants-in-aid to school districts.[380] Assuming that an appropriation is available for the purpose of the specific program, special apportionments may be granted for expanding children's education and learning (EXCEL) projects, which could include an education technology project which, as a primary purpose, enhances the use

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[372] Ibid §40:9D-2.
[373] Ibid §40:9D-3.
[374] For example, in 2015, a bill was introduced to the New York City assembly with the intent of creating a broadband authority authorizing statewide cable franchises for the purpose of competitive cable service and promoting the wide-spread development of high-capacity broadband Internet access. New York State Assembly. Bill A02118. http://nyassembly.gov/. Available at http://nyassembly.gov/leg/?default_fld=&leg_video=&bn=A02118&term=2015&Summary=Y&Text=Y.
[375] New York State Assembly. Consolidated Laws. http://nyassembly.gov/leg/. Available at http://public.leginfo.state.ny.us/lawssrch.cgi?NVLWO:.
[376] New York Public Service Statute, Article 1, §§4-5.
[377] New York Public Service Statute, Article 5.
[378] Basic services consist of residential, individual business, and public access line network access, connection charges for such network access, local usage, local coin usage rates, tone dialing, access to emergency services, statewide relay services, operator assistance services, director listings, and provisions that affect privacy protections. New York Public Service Statute, Article 5, §92(2)(a).
[379] New York Education Statute, Article 5, §92-g.
[380] New York Education Statute, Article 73, §3641.

of technology including instructional content with video streaming, Internet connections, fiber optics, telecommunication systems, and wireless options.[381]

State Technology Law: Article 1 of the State Technology Law establishes the Office of Information Technology Services.[382] Among other things, the Office advises and assists state agencies in developing policies, plans and programs for statewide coordination, administration, acquisition, and deployment of technologies; establishes, oversees, manages, coordinates, and facilitates the planning, design and implementation of the state's common technology networks; and provides technology services via agreements with municipal corporations, public authorities, and any unit of the State University and City University of New York.[383]

North Carolina:

North Carolina laws that apply to wireless broadband include various statutes that contain rules for counties, cities and towns, and state lands, as well as the State's statute concerning public utilities.[384] The North Carolina Public Utilities Act (Chapter 62) authorizes the North Carolina Utilities Commission to regulate public utilities generally, their rates, and services and operation.[385] Additionally, as discussed below, North Carolina's regulations concerning counties (Chapter 160A) impact state public communications initiatives.

Public Utilities Act: Notably, although the North Carolina Utilities Commission may develop regulatory policies to govern the provision of telecommunications services, broadband services, defined as any service that consists of or includes a high-speed access capability to transmit at a rate of not less than 200 Kbps, is considered by the Public Utilities Act to be sufficiently competitive as not to be subject to regulation by the Commission.[386]

Executive Organization Act of 1973: North Carolina's Executive Organization Act creates the Industrial Development Fund Utility Account to provide funds to assist local government units of the most economically distressed counties in North Carolina in creating jobs.[387] The funds are to be used for construction or improvements to new or existing infrastructure, including telecommunications and high-speed broadband.[388]

Local and State Land Laws: Both the North Carolina statutes governing county and city and town rules expressly state that it is State policy to facilitate the placement of wireless communications support structures in all areas of North Carolina.[389] They further stipulate that the placement, construction, or modification of wireless communications facilities shall be in conformity with the Federal Communications Act as

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[381] Ibid. §3641(14)(b)(1)(ii)(a).
[382] New York State Technology Law, Article 1.
[383] New York State Technology Law, Article 1, §103.
[384] North Carolina General Assembly. North Carolina General Statutes. http://www.ncleg.net. Available at http://www.ncleg.net/gascripts/Statutes/StatutesTOC.pl.
[385] North Carolina Chapter 62, §62-2(b).
[386] North Carolina Chapter 62, §62-2(b1), §62-3(1).
[387] North Carolina Chapter 143B, §143B-437.01(a).
[388] Ibid §143B-437.01(a)(1).
[389] North Carolina Chapter 153A, §153A-349.50. North Carolina Chapter 160A, §160A-400.50.

amended by the Federal Middle Class Tax Relief and Job Creation Act of 2012 and in accordance with FCC rules.[390] North Carolina's Chapter 146 regarding unallocated state lands limits selection for communications towers or antennas in the State Parks System to locations that minimize the visual impact on the surrounding landscape and apply this rule to city and county ordinances.[391]

However, the North Carolina statute governing cities and towns also serves to impede public communications initiatives. In particular, Article 16A imposes several requirements on city-owned communications services. These include limiting the provision of communications services to within corporate limits of the city; refraining from advertising or promoting city-owned communications services on public, educational, or governmental access channels if another communication service carries the channel; and not subsidizing service (e.g., pricing below cost).[392] Moreover, prior to undertaking to construct a communications network for the provision of communications service, a city must first solicit proposals from private business.[393] The city may proceed to provide communications service only after the breakdown of negotiations with the first and if applicable, second private proposal to offer service following 60 days of negotiation per private proposal.[394]

In 2014, the City of Wilson, North Carolina, which provided 1 Gbps broadband service in Wilson County, North Carolina, sought to expand service, but was precluded from doing so by Article 16A of Chapter 160A.[395] The City sought to preempt the applicable sections and the FCC concluded that such preemption would remove barriers to overall broadband investment and promote overall competition in North Carolina. Although the FCC did not preempt Article 16A in its entirety, it did preempt certain measures deemed to raise economic costs or cause delay for municipal broadband service provision.[396] However, this preemption was overturned on August 2016 by the United States Court of Appeals for the Sixth Circuit, which determined that the FCC did not have authority to preempt North Carolina's laws.[397]

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[390] Ibid.
[391] North Carolina Chapter 146, §146-29.2(e), §146-29.2(f).
[392] North Carolina Chapter §160A, §160A-340.1.
[393] Ibid, §160A-340.6(a).
[394] Ibid §160A-340.6(f).
[395] Federal Communications Commission (2015). "City of Wilson, North Carolina Petition for Preemption of North Carolina General Statute Sections 160A-340 et seq., et al." Memorandum Opinion and Order in WC Dockets No. 14-115, 14-116. Adopted Feb. 26, 2015. Released Mar. 12, 2015. ("2014 NC and TN Local Petitions MO&O"). At ¶ 3. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-25A1_Rcd.pdf.
[396] Ibid at ¶181.
[397] United States Court of Appeals for the Sixth Circuit (2016). "State of Tennessee (15-3291); State of North Carolina (15-3555), Petitioners, National Association of Regulatory Utility Commissioners, Intervenor, v. Federal Communications Commission; United States of America, Respondents, Electric Power Board of Chattanooga; City of Wilson, N.C., Intervenors." On Petitions for Review of an Order of the Federal Communications Commission. No 15-25. Argued Mar. 17, 2016. Decided and Filed Aug. 10, 2016. Available at http://www.opn.ca6.uscourts.gov/opinions.pdf/16a0189p-06.pdf.

Wisconsin:

Wisconsin Chapters 66 and 196 are the primary statutes that impact broadband deployment in Wisconsin.[398] Chapter 196 specifies the regulation of public utilities for the State, including setting out the jurisdiction of the Wisconsin Public Service Commission to supervise and regulate every public utility in the State.[399] Chapter 66 lays out laws governing Wisconsin municipalities.

Chapter 196: Although a telecommunications utility—an entity that provides telecommunications services directly to the Wisconsin public—is defined in Wisconsin as a public utility under the jurisdiction of the Public Service Commission, a telecommunications service consists of the conveyance of *voice* communication regardless of technology and does not refer to broadband data service in the statute.[400] However, the Public Service Commission does administer the broadband expansion program, Broadband Forward![401] This program is designed to make broadband expansion grants to eligible applicants for the purpose of constructing broadband infrastructure in underserved areas.[402]

Chapter 66: The laws that are relevant to wireless broadband provision in Wisconsin's Municipal Law include tower siting regulations and restrictions on municipal broadband. Section 66.0404 of the Municipal Law lays out mobile tower siting regulations, specifying rules on construction, modification, and collocation similar to those discussed in Section 3.1 discussing Federal tower and antenna siting.[403]

Chapter 66 Section 66.0404 restricts local government (city, village, or town) communications initiatives. In particular, with some exceptions, local governments are only permitted to operate facilities for providing video, telecommunications, or broadband services if the local government first holds a public hearing on the proposed ordinance prior to which it must provide a report estimating total costs of and revenues derived from constructing, owning, or operating the facility for public inspection.[404]

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[398] Wisconsin State Legislature. Chapter 66. https://legis.wisconsin.gov/. Available at http://docs.legis.wisconsin.gov/statutes/statutes/66; Wisconsin State Legislature. Chapter 196. . https://legis.wisconsin.gov/. Available at http://docs.legis.wisconsin.gov/statutes/statutes/196.
[399] Wisconsin Chapter 196, §196.02.
[400] Ibid.
[401] Ibid §196.504.
[402] Ibid.
[403] Wisconsin Chapter 66, §66.0404.
[404] Ibid §66.0422(2).

4. COMPARISON AND EVALUATION OF DIFFERENT SPECTRUM BANDS

Whereas Section 2 explores at length various spectrum bands that we considered to be useful in the provision of broadband Internet service, in that section, we focused on individual bands to a large degree outside of the economic, geographic, and social context that is explored at length in the accompanying business strategy and case analysis. Moreover, we looked at each band or set of bands largely in isolation. In this section, we provide a brief overview of different aspects of the various spectrum bands explored above for the purposes of comparison for potential service providers seeking to determine the most appropriate bands for different contexts. Although the various contextual factors are explored for the most part in the accompanying business strategy and case analysis, we nevertheless hope that this section at a glance helps to facilitate cost and benefit analysis that could inform which bands are more suitable for different contexts.

4.1. Spectrum Licensing Overview

Before delving into the costs and benefits of using different spectrum bands, it is worthwhile to summarize the various spectrum licensing schemes that have been described for individual bands in Section 2. Broadly, we classify these into four categories: (1) geographic licensing, (2) unlicensed and license-by-rule, (3) non-exclusive nationwide licensing, and (4) site (or system) based licensing. Table 2 organizes the major spectrum bands discussed in Section 2 according to licensing scheme.

Table 2: Licensing According to Spectrum Band

License Type	Spectrum Bands
Geographic licensing	Mobile Wireless (700 MHz, Cellular, SMR, PCS, AWS, WCS, BRS, EBS); 3.5 GHz (PALs); Spectrum Frontiers (24 GHz, 28 GHz, Upper-37 GHz, 39 GHz)
Unlicensed / License-by-rule	TVWS; Wi-Fi (900 MHz, 2.4 GHz, 5GHz); 3.5 GHz (GAA); Lower-37 GHz; 60 GHz; 90 GHz (indoors)
Non-exclusive nationwide licensing	3650-3700 GHz; 70/80/90 GHz
Site based licensing	Fixed Microwave (6 GHz, 11 GHz, 18 GHz, and 23 GHz)

As discussed in Section 2, depending on the band, geographic based licenses are exclusive over some predefined geographic area, either one consisting of a standardized geographic metric such as those provided by the U.S. Census Bureau (e.g., Census Tracts for Citizens Broadband Radio Service Priority Access Licenses; Cellular Market Area, Major Trading Area, or Major Economic Area for different mobile wireless licenses) or a circle defined by a radius around a base station (as in EBS).

In contrast, equipment that relies on unlicensed spectrum and spectrum that is licensed by rule does not require a license to operate, but is also not protected from harmful interference nor permitted to cause harmful interference to incumbent or other priority operations. A license-by-rule approach provides individuals, organizations, and service providers with "automatic" authorization to deploy small cell or other systems, in much the same way that Part 15 unlicensed rules authorize TVWS or Wi-Fi devices.[405] For instance, Citizens Broadband Radio Service GAA users may use only certified FCC-approved Citizens Broadband Radio Service Devices and must register with the SAS (albeit according to rules set out in Parts 95 and 96 instead of Part 15).[406]

Site-based licenses and non-exclusive nationwide licenses provide a middle ground between the above licensing regimes, which are appropriate for the point-to-point and point-to-multipoint applications in the bands licensed as such. Site-based licensing entails frequency coordination and the filing of an application for each set of sites comprising a link. Non-exclusive nationwide licenses function similarly, requiring link registration, but instead of individual licenses applying to individual links, there is a single non-exclusive nationwide license (and associated licensing fee).

4.2. Costs and Benefits

The tradeoffs between different bands depends on a large number of factors and although certain bands are often preferred for particular contexts—for instance, the 6 GHz band is typically preferred for long links over water and television white spaces are often relied on in difficult terrain when cost is a major factor, but bandwidth is not—in general, multiple bands can be substituted for one another. The choice of band thus typically balances costs with needs.

Costs:

The costs of wireless broadband provision consist of capital expenditures (CAPEX) and operating expenses (OPEX). CAPEX in wireless broadband provision typically involves network core investment and the connection of sites and base stations to the core network. This greatly varies with the magnitude of the project (e.g., expected number of users and geographic scope). Additional major CAPEX involves costs of constructing infrastructure (e.g., towers) when existing infrastructure does not exist and site preparation as necessary. Site preparation might include procuring power and protected power, space for electronics (including antennas), and connecting to backhaul. Other CAPEX includes connecting routing equipment and base stations, licensing for ancillary equipment when applicable (e.g., if the project includes proprietary user devices). Finally, spectrum licensing costs may be a factor depending on the band used.

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[405] Federal Communications Commission (2012). "Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band." Notice of Proposed Rulemaking and Order in GN Docket No. 12-354. Adopted Dec. 12, 2012. Released Dec. 12, 2012. At ¶ 11. Available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-12-148A1_Rcd.pdf.

[406] Ibid at ¶ 162.

OPEX includes employee salaries (e.g., for site maintenance), tower or infrastructure and/or equipment space rents, power, backhaul (leases), and other general ongoing expenditures such as insurance, utilities, licenses and memberships, office supplies, and repairs.

Table 3: Spectrum Cost Related Factors

Spectrum Band	License Cost[407]	License Term[408]	Antenna Height[409]
TVWS	None	N/A	4 feet
EBS	Varies[410]	10 years	3 feet
2.4 GHz Wi-Fi	None	N/A	5 feet[411]
5 GHz Wi-Fi	None	N/A	
6 GHz	$295 per link	10 years	6-12 feet[412]
11 GHz	$295 per link	10 years	1-6 feet
18 GHz	$295 per link	10 years	
23 GHz	$295 per link	10 years	1 foot
24 GHz	Varies[410]	10 years	
39 GHz mmW	Varies[410]	10 years	
60 GHz mmW	None	N/A	1/2 foot
70/80 GHz mmW	$295[413]	10 years	1 foot

[407] When applicable, license costs are based on the schedule of charges for applications and other filing in the wireless telecommunications services available in 47 C.F.R., Part 1, Subpart G. The schedule was most recently updated on July 27, 2016. 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=c84695657a9038d32d4295b1e928356c&mc=true&node=pt47.1.1&rgn=div5#se47.1.1_11102.

[408] License terms are based on the different sections of the C.F.R. discussed in Section 2, that pertain to the band in question. License terms are the maximal terms provided in the C.F.R., and might be shorter under certain circumstances.

[409] Antenna heights are rough approximations based on our conversations with various manufacturers, vendors and ISPs. They do not necessarily represent minimal antenna heights. Antennas vary in shape and size (e.g., unidirectional vs. omnidirectional) and quoted sizes do not include equipment used to mount the antenna.

[410] As our discussion of waivers filed by NMU shows, EBS licenses that have not previously been issued by the FCC are available for free to eligible institutions. Elsewhere, EBS licenses are available on the secondary markets, and consequently the costs depend on market characteristics and the relative bargaining power of existing licensees willing to transfer their licenses. Similarly, 24 GHz and 39 GHz licenses were initially auctioned based on Economic Areas and are likewise available on the secondary markets.

[411] This refers to a point-to-point or point-to-multipoint (base) antenna.

[412] Long-haul links that rely on the 6 GHz band often require space diversity, which entails separate antennas for transmission and reception (at each end).

[413] The fee for an initial non-exclusive nationwide license is $295. Individual link registrations are not subject to FCC application or regulatory fees. However, Database Managers registering individual links may charge fees in order to recoup costs associated with the link registration system. 2005 mmW Public Notice §F.

Because CAPEX and OPEX can vary drastically with the project scope, topography, and the existing level of development, and moreover, the focus of this analysis is primarily regulatory and technical, in Table 3, we specifically hone in on the two cost related factors that are largely driven by the combination of regulation and spectrum properties: license costs and base antenna heights. Antenna sizes are relevant for both CAPEX and OPEX because they can influence the size of infrastructure necessary to mount the antenna, which impacts both initial construction and installation as well as site leasing. Sufficiently small antennas may be mounted on existing poles and other standing structures or rooftops, whereas overly large antennas could require new tower construction. When referring to antenna size, we specifically focus on the base antenna height at a location that connects to the core network (i.e., where backhaul is available). These are the antennas that extend the core (wireline) network to the "last mile," that is, to areas that the core network would otherwise not reach. In the case of point-to-point links, an antenna is required at each end. Unfortunately, in most instances, we were not able to obtain complete antenna dimensions for a more precise size estimate.

When comparing license costs, we advise that readers view them bearing in mind the different licensing regimes in Table 2 because licenses across different regimes are not directly comparable with one another. For example, license costs for point-to-point links in the 6 GHz to 23 GHz bands are for individual links or paths, whereas EBS licenses provide exclusive use over a circular region with a 35 mile radius and 24 GHz spectrum is licensed on an Economic Area basis. Additionally, for unlicensed spectrum, we do not include charges for equipment approval for the FCC because these are costs that are included in the price of equipment from certified equipment manufacturers or vendors.

Benefits:

As we discussed in Section 2, spectrum bands vary substantially in their propagation characteristics. Moreover, the capabilities of different spectrum bands also depend on regulations—which in addition to specifying a licensing scheme, may stipulate different emission and power limits, which could influence the technology used for different bands. Additionally, the FCC has made vastly different amounts of spectrum available in different bands for different uses. All of these factors combine to influence the type of service that could be offered. In Table 4, we provide a side by side comparison of how these characteristics ultimately work together to impact two of the main factors related to use of wireless spectrum for the provision of broadband service—maximum throughput and distance over which service is typically made available from the base antenna. The figures in Table 4 represent rough approximations of typical deployment specifications based on our conversations with various manufacturers, vendors and ISPs, and are not necessarily representative. The table also focuses on technologies in use during the writing of the report, and is hence intentionally conservative.

We note that these comparisons are somewhat imperfect across bands, because whereas lower frequency spectrum such as TVWS and EBS might be used to provide mobile or point-to-multipoint service, possibly without relying on line-of-sight, higher frequencies require an unobstructed path between antennas. Nevertheless, as technology evolves and rules that govern spectrum are modified to reflect these changes—as was the case in the Spectrum Frontiers Report and Order, which permitted mobile wireless use for certain mmW bands and contemplating extending

similar rules to other bands—bands which are presently relied on for very specific purposes (e.g., point-to-point backhaul links) may start to be used in novel ways.

Table 4: Throughput and Distance by Spectrum Band

Spectrum Band	Maximum Throughput	Distance
TVWS	10-33 Mbps[414]	2-10 km (1.2-6.2 mi)
EBS	100-150 Mbps[415]	4.8-14.5 km (3-9 mi)[416]
2.4 GHz Wi-Fi	60 Mbps	6.4-24 km (4-15 mi)[417]
5 GHz Wi-Fi	1-5 Gbps[418]	6.4-200 km (4-124 mi)[417]
6 GHz	400-800 Mbps	35 km (22 mi)
11 GHz	400-1,000 Mbps	16-29 km (10-18 mi)
18 GHz	500 Mbps[419]	16 km (10 mi)[419]
23 GHz	1-4 Gbps	3.2-4.8 km (2-3 mi)
24 GHz	1 Gbps	0.8-1.6 km (0.5-1 mi)[420]
39 GHz mmW	1 Gbps	
60 GHz mmW	200-1,000 Mbps	
70/80 GHz mmW	1-2 Gbps	1.6 km (1 mi)

In addition, ranges for throughput and distance in Table 4 should be treated independently in the sense that the maximum number for a throughput range does not necessarily correspond to the maximum for distance. Moreover, distance is impacted by geography, equipment power, and obstructions for spectrum that does not rely on line-of-sight connectivity. Finally, maximum throughput represents throughput across all users. When there are multiple simultaneous users, throughput should be divided by the number of users.

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[414] The 10 Mbps represents a single 6 megahertz channel whereas 33 Mbps represents equipment that can bond two 6 megahertz channels (from a different vendor). Certain vendors have stated that they hope to increase optimum throughput to as much as 100 Mbps in the future by bonding multiple channels.

[415] 100 Mbps represents a single 22.5 megahertz block without “cell splitting,” whereas 150 Mbps represents a deployment that adds an additional 5 megahertz. If the base station is instead, say, split into six directional antennas, throughput could be increased six-fold.

[416] Unlike TVWS, in which the base antenna communicates with a device that then provides Wi-Fi to users, EBS can presently be used to communicate directly with user devices. However, with longer distances such as 9 miles, an additional device may need to be installed closer to users’ premises to amplify the signal.

[417] This distance refers to a point-to-point or point-to-multipoint deployment.

[418] Because Wi-Fi is unlicensed, interference is a major concern and higher throughput generally refers to more rural deployments.

[419] We note that the maximum throughput and distance figures for the 18 MHz band were obtained from different ISPs. Thus, the 500 megahertz deployment does not necessarily refer to a 10 mile distance.

[420] Unlike with other bands that are 6 GHz or higher and which are presently typically relied on for point-to-point connectivity, the 24 GHz band is presently used for point-to-multipoint coverage using sectorized antennas.

4.3. General Themes

A number of general themes emerge upon examination of our findings in Tables Table 2 through Table 4 along with a synthesis of Section 2.

There are substantial differences in licensing across bands:

As Table 2 shows, there are various licensing regimes across spectrum bands. Moreover, licensing regimes do not appear to have an obvious pattern as frequencies increase: with the exception of site or link based licenses used in fixed microwave services bands, other licensing regimes can be found over a broad range from as low as below 1 GHz spectrum up through the mmW bands.

We view this diversity in licensing as arising from regulatory efforts to balance existing uses and technologies with the potential for future developments. For instance, spectrum that is unlicensed, and considered by many to be useful for wireless innovation can be found at the lowest range of the bands that we explore (TVWS) as well as toward the top of that range (60 GHz mmW). At the same time, exclusively geographic based licenses and site based licenses, which also have a broad range, provide the requisite exclusivity for maintaining and expanding on existing services.

There is a(n imperfect) tradeoff between maximum distance and throughput:

Table 4 shows that on balance, as the spectrum frequency increases, the maximum throughput rises, and to some degree distance falls, albeit with a number of caveats. First, the lower frequencies in the table—particularly TVWS and EBS—are presently used for mobile wireless broadband or point-to-multipoint configurations, and may not be designed with complete line-of-sight in mind. Thus, the tradeoff between maximum distance and throughput is best looked at from the perspective of a comparison of point-to-point configurations of bands other than TVWS and EBS. However, even then, the tradeoff is imperfect, driven in part by aggregate spectrum availability, technological developments at certain wavelengths, and regulations.

Many of the bands that are 5 GHz and above are capable of 1 Gbps backhaul, thus to a certain degree, the tradeoff may be one of distance versus costs. As can be seen from observing Table 3, higher frequency bands can depend on substantially smaller sized antennas, which could reduce infrastructure related costs. Additionally, the 5 GHz band, is unlicensed and therefore may be inappropriate for long distance urban deployments.

Low frequencies for mobility versus higher frequencies for backhaul:

To a large degree, frequencies below 3 GHz are currently useful for mobile wireless broadband or point-to-multipoint service. However, although these bands can extend the reach of broadband beyond an existing wireline network—and in that sense, their use may be referred to as backhaul—at current technologies, these bands generally provide throughput measured in megabits per second, not gigabits per second. In contrast, although most frequencies above 3 GHz are used for point-to-point connections that require line-of-sight, they may, under certain circumstances, substitute for wireline backhaul when the economics of broadband expansion do not justify wireline network expansion. In particular, as Table 4 shows, throughput available from many fixed microwave service and millimeter wave band installations is measured in

gigabits per second. In many instances, these installations provide sufficient bandwidth for residential and other needs. Nevertheless, even though bandwidth measured in gigabits compares favorably to older generation copper and coaxial cable networks, it cannot necessarily compete with the capacity available from fiber installations, which can often be measured in terabits.

5. CONCLUSION

In this report, our goal was to inform readers of the evolving regulatory and technological landscape that permits service providers to offer wireless broadband in areas where wireline networks are not available. These services can be crucial for meeting broadband demand in areas where private competitors have determined that wireline expansion is unprofitable and can serve to bridge digital divides in highly rural or economically distressed areas.

Although in this report, as well as in the accompanying business strategy and case analysis, we have explored a number of potential wireless broadband alternatives, neither report should be viewed as exhaustive, as various other spectrum bands and business strategies are available to support wireless broadband service. In particular, we focused largely on spectrum bands that could be implemented and cases that might be replicated by educational, non-profit, and community anchor institutions rather than on alternatives that may additionally be feasible for major for-profit service providers.

Additionally, both reports represent snapshots of a service that has been for decades and continues to rapidly evolve. Changes in the competitive and technological landscape with regard to wireless broadband force regulators to constantly revise the rules that govern different spectrum bands. For instance, at the time of the writing of this report, the FCC had only recently released its Spectrum Frontiers Report and Order, which among other things granted mobile operating rights to existing 39 GHz band licenses. Moreover, in its simultaneously released FNPRM, the FCC contemplated expanding mobile rights to other mmW frequency bands. Coupled with these more flexible use rights, developments in technology could allow for mobile broadband in frequency bands that had not previously been envisioned for such service at service speeds that are not possible with the limited quantities of spectrum presently relied on for mobile broadband.

Ongoing developments at lower frequencies could similarly impact the provision of wireless broadband. For example, although the grant of mobile operating rights in the mmW bands has the potential to improve broadband availability and speeds in urban areas, because of their limited propagation, such bands are less likely to provide similar benefits in rural parts of the U.S. Conversely, the greater availability of TVWS and unused EBS in rural areas better serve in these parts of the country. However, both bands are subject to a degree of regulatory uncertainty. For instance, the availability of TVWS could be impacted by the FCC's Incentive Auction.

Conversely, EBS is presently unavailable in areas where it has not already been assigned without filing a detailed waiver proposal and the FCC has not acted on the aforementioned 2014 consensus proposal. This hesitancy on the part of the FCC may be due to its obligation to resolve mutually exclusive application for initial licenses in most bands by using auctions, something that the consensus proposal attempts to get around.[421] Moreover, auctions are more likely to assign spectrum to an applicant that

[421] Federal Communications Commission. About Auctions. www.fcc.gov. Available at http://wireless.fcc.gov/auctions/default.htm?job=about_auctions.

values it most, something that the consensus proposal fails to do. On the other hand, because EBS spectrum is intended for educational use, the FCC may be unwilling to have local governments and institutional bid against each other in an auction that ultimately funds the Federal government. One alternative may be to design a budget-balanced auction, in which the winning bids are redistributed to the auction participants according to some mechanism. However, it may be difficult to design a budget-balanced multi-unit auction (there are up to five 22.5 megahertz blocks of EBS in each geographic region) that is also strategy-proof, whereby it is always a dominant strategy for bidders to bid their true valuation for each block of spectrum.

Given our focus on implementation by non-profit and community institutions, an important additional consideration concerns Federal and other funding mechanisms for wireless broadband deployment. In the accompanying business strategy and case analysis we briefly discuss a recent FCC Public Notice notifying the public about a petition requesting that the FCC allow E-rate subsidized broadband networks to be accessed by students at home for educational purposes without an obligation on the E-rate applicant to cost allocate the portion of the traffic attributable to off-campus use.[422] However, we have largely abstracted from investigating funding mechanisms more generally in either report. This may be a direction for future research that is of considerable interest to potential wireless broadband service providers.

[422] 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 http://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0919/DA-16-1051A1.pdf.

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.[423] 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.[424] 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.[425] 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.[426]

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.[427] 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.[428] 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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[423] The Quilt. About Us. www.thequilt.net. Available at http://www.thequilt.net/about-us/.
[424] Merit. About Us. www.merit.edu. Available at https://www.merit.edu/about-us/.
[425] Merit. Merit's History. www.merit.edu. Available at https://www.merit.edu/about-us/merits-history/.
[426] Merit. Services. www.merit.edu. Available at https://www.merit.edu/services/.
[427] MCNC. About MCNC. www.mcnc.org. Available at https://www.mcnc.org/about.html.
[428] 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.[429]

NJEDge: NJEDge is a non-profit technology consortium of academic and research institutions in New Jersey.[430] 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.[431] 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.[432] 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.[433] 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.[434] 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.[435]

Appendix 2: The Research Team

This report was written jointly by Aleks Yankelevich and Mitch Shapiro, with substantial guidance and help from Bill Dutton and Derek Murphy as well as support from other experts at Michigan State. Aleks Yankelevich is an industrial organization economist and Mitch Shapiro is a telecommunications specialist. Bill Dutton, the Director of the Quello Center, is an expert in media and information, as well as Internet studies, and Derek Murphy is an expert in strategic planning and policy development. The authors

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[429] MOREnet. The MOREnet Network. www.more.net. Available at https://www.more.net/content/morenet-network.
[430] NJEDge.Net. About Us. www.njedge.net. Available at http://njedge.net/about-us/.
[431] NJEDge.Net. Background. www.njedge.net. Available at http://njedge.net/about-us/organization-background-history/.
[432] NYSERNet. About NYSERNet. www.nysernet.org. Available at https://www.nysernet.org/about-nysernet/about-us/.
[433] WiscNet. Home. www.wiscnet.net. Available at http://www.wiscnet.net/.
[434] WiscNet. WiscNet Network Services. www.wiscnet.net. Available at http://www.wiscnet.net/network-services/.
[435] WiscNet. WiscNet Members. www.wiscnet.net. Available at http://www.wiscnet.net/members/.

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.

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.

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 business strategy and case 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.

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.

***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.