Appendix 5

Supplemental Information—Broadband Technologies

Overview

On November 7, 2018 the Rural Broadband Task Force formed the Broadband Technologies Subcommittee to review “the feasibility of alternative technologies and providers in accelerating access to faster and more reliable broadband service for rural residents.” Subcommittee members include Zachary Hunnicutt, Ron Cone, and Dan Spray. In addition to alternative technologies, subcommittee members also included a review of technologies currently being used to deploy broadband to provide a frame of reference.

Here is the list of technologies reviewed by the Rural Broadband Subcommittee:

- Wireline Technologies—Digital Subscriber Line (DSL)
- Wireline Technologies—Fiber
- Power Line Technologies—AirGig
- Fixed Wireless—TV White Space
- Fixed Wireless—Millimeter Wave
- Fixed or Mobile Wireless—Educational Broadband Service (EBS)
- Fixed or Mobile Wireless—Citizens Broadband Radio Service (CBRS)
- Mobile Wireless—5GSatellite—Low Earth Orbit

Wireline Technologies—Digital Subscriber Line (DSL)

Description	This family of technologies (including ADSL2+, VDSL, VDSL2) provides internet access by transmitting digital data over a local telephone network.
Bandwidth Capabilities	1.5 Mbps up to 50-100 Mbps using the newest xDSL protocols. Speeds are distance dependent and are often provided as asymmetric bandwidth. Current VDSL@ standards provide 100 Mbps @ 500 meters maximum distance. Typical ADSL speeds are 24/3 Mbps depending on distance.
Effective Distance	5.5 km (18,000 feet) without a repeater
Scalability/Future Proof	Except at short distances, DSL probably won't provide the speeds--especially upload speeds-needed by consumers in the future.
Typical Construction Costs Per Subscriber	$655-$1100
Barriers	Distance limitations of using existing cable infrastructure to meet increasing bandwidth needs
Pros	Uses the existing telephone network; can be bundled/unbundled with traditional voice service
Cons	Very distance sensitive, higher quality cable allows longer distance Asymmetric
Overall Feasibility	Currently widely used, but may not be the best technology for future needs.
Sources and Links	**Broadband 101 Video with Jason Axthelm, Nebraska Broadband Today Conference 2017** **Whatis.com** **Broadband Recommendations: Meeker County, Minnesota County by Design Nine (August 2018)**

Wireline Technologies—Fiber

Description	Fiber technology converts electrical signals to optical laser signals carrying data
Bandwidth Capabilities	Up to 10 Gbps or more. An upper limit has not been found.
Effective Distance	Up to 25 miles (Passive Optical Network/PON Fiber) and up to 50 miles (Active Ethernet)
Scalability/Future Proof	Scalable and future proof
Typical Construction Costs Per Subscriber	$3,250-$3,500
Barriers	Expensive to deploy due to build costs
Pros	Up to 10 Gbps or more. Fiber has a life expectancy of 30-40 years or more.
Cons	Expensive to deploy
Overall Feasibility	May be too expensive to deploy in rural areas without additional support
Sources and Links	**Broadband 101 Video with Jason Axthelm, Nebraska Broadband Today Conference 2017**

Wireline Technologies—Cable Modem

Description	Cable providers deliver broadband using the same coaxial cable used to deliver cable TV service using DOCSIS (Data over Cable Service Interface Specification). This is a shared bandwidth service.
Bandwidth Capabilities	Up to 10 Gbps down/1 Gbps up using DOCSIS 3.1
Effective Distance	Up to 100 miles
Scalability/Future Proof	The asymmetric nature of cable modem service is a limitation for some consumers and will likely be more of an issue in the future.
Typical Construction Costs Per Subscriber	$2,500 to $3,500
Barriers	Cable modem technology is usually only deployed within towns.
Pros	Good download speeds and generally one of the more affordable options for consumers in towns
Cons	Asymmetric and shared bandwidth service
Overall Feasibility	Since cable service is typically only available within city limits, cable modem service isn't a feasible technology for reaching rural areas outside of town.
Sources and Links	Broadband 101 Video with Jason Axthelm, Nebraska Broadband Today Conference 2017

Power Line Technologies—AirGig

Description	AirGig is being tested by AT&T with a reported availability date of 2021. AirGig uses antenna modules called eggs which are clamped on power lines to send data signals which cling to the wire. A demonstration in September 2018 showed data capacity of 90 gigabits per second (Gbps). To link to a home, AT&T will likely use more conventional wireless equipment like 5G mobile networks. AT&T began testing the technology with Georgia Power in 2017. In January 2019, AT&T said it is discussing testing and building commercial-grade AirGig equipment with suppliers.
Bandwidth Capabilities	Possibly 100 Mbps
Scalability/Future Proof	Unknown
Barriers	Public power providers could not provide telecommunications services directly, but could partner with telecommunications providers.
Pros	Power line infrastructure is in place which may reduce implementation costs.
Cons	Power line infrastructure is vulnerable to damage due to severe weather events such as ice storms or tornadoes.
Overall Feasibility	Potentially promising
Sources and Links	Stephen Shankland. AT&T AirGig could mean 100-megabit rural broadband in 2021. (Sept. 10, 2018) C|Net Joan Engebretson. AT&T plans to test 5G with AirGig, Seeks AirGig Manufacturers (Jan. 30, 2019). Telecompetitor

Wireless Spectrum Overview

Bands	Spectrum Range	Coverage v. Capacity
Low-Bands TV White Space 554-698 MHz	Below 1 GHz	Offer greater coverage due to longer range and building penetration, but less capacity.
Mid-Bands Millimeter Wave 2.4 Ghz, 5 GHz Educational Broadcast Service (EBS) 2495-2690 GHz Citizens Band Radio Service (CBRS) 3550-3700 MHz Wireless Fiber 3700-4200 MHz	2 GHz to 6 GHz	Offer a combination of coverage and capacity.
High-Bands Millimeter Wave 30-300 GHz	Above 24 GHz	Offer enormous capacity, but limited propagation. Good for short distances and line of sight.

The FCC currently has spectrum sharing proceedings open on TV White Space, Citizens Band Radio Service, "Wireless Fiber," Educational Broadband Service (EBS), and Extending Unlicensed and Wi-Fi Across 6 GHz.

Source: SHLB webinar on Key Concepts in Spectrum Policy, Feb. 2019.

Fixed Wireless—TV White Space

Description	Point to multipoint wireless Internet delivery via unlicensed UHF frequencies in the 470-698 MHz range. "White Space" refers to the unoccupied channels previously used to deliver television broadcasts.
Bandwidth Capabilities	3-24 Mbps Future TVWS technology may allow for channel bonding and aggregation of up to 60 Mbps.
Effective Distance	~3-6 miles Line-of-Sight (LOS) delivery. Less than that distance with Non-Line-of-Sight (NLOS) delivery.
Scalability/Future Proof	Developing technology, current FCC regulations limit the effectiveness of this technology specifically in truly rural areas. The FCC recently increased the limitation on antenna height above ground level from 30 meters to 100 meters. The FCC is considering auction of the upper TVWS channels above channel 37, thereby leaving channels 14-36 for open development.
Typical Construction Costs Per Subscriber	~$1,000-$1,500 in rural areas. Current sectors are only able to support ~20 clients, but range does not allow for sparsely populated areas to reach that density therefore raising the per subscriber cost. **Estimated Costs:** Base station $5,000-$15,000 plus customer premise equipment $300-$700 per site
Typical Operational Costs Per Subscriber	~$20-$40/month depending on delivered speeds
Barriers	Current FCC regulations and costs per subscriber in low density areas
Possible Incentives	This technology could work well in rural communities and customer sites just outside of city limits, incentivizing the technology buildout in those areas would be useful.
Pros	Capable of delivering NLOS broadband
Cons	Short distance ranges and bandwidth limits for NLOS delivery, until equipment improves
Overall Feasibility	TV white space may be suited for lower bandwidth agricultural internet of things applications. With Microsoft's support, the cost of customer service equipment has been coming down. Future reductions in the

	prices of customer service equipment to about $100 would likely make this technology economically feasible.
Sources and Links	

Fixed Wireless—Millimeter Wave

Description	Point-to-Multipoint 2.4Ghz, 5Ghz, 24Ghz and 60Ghz Wireless
Bandwidth Capabilities	Varied from 5 Mbps to 2.5 Gbps based on frequency and distance
Effective Distance	Varied from .6 miles to 15 miles
Scalability/Future Proof	Quite scalable and actively developed, well supported by the FCC rulings.
Typical Construction Costs Per Subscriber	~$200-$1,500 depending on frequency and distance
Typical Operational Costs Per Subscriber	~$30-$90 per month depending on bandwidth provided to the client
Barriers	These frequencies are limited to line of site and power per the FCC.
Possible Incentives	Higher density builds need to be used to adequately provide services to rural areas. Incentives for building towers and providing power to the structures could increase the profit model and make it more feasible.
Pros	Solid technology that's been around and is well supported by the FCC. Able to deliver high rate of speed at respectable distances.
Cons	Technology still needs FCC approval for higher powers in rural areas. Technology is limited to LOS delivery, this gets difficult in both urban and rural areas.
Overall Feasibility	This is a mainstream solution that needs to be well supported due to low cost of delivery

Fixed or Mobile Wireless—Educational Broadband Service (EBS)

Description	Educational Broadband Service (EBS), formerly known as the Instructional Television Fixed Service (ITFS), 2.5GHz (2495-2690 MHz) spectrum, is a high-speed, high-capacity wireless broadband service, including two-way Internet service via cellularized communication systems. Previously, only accredited educational institutions and nonprofit educational organizations could hold EBS licenses, limited to a 35-mile radius Geographic Service Area, although licensees can lease their excess capacity to commercial providers (e.g. Sprint). On July 11, 2019, the FCC released a Report and Order that will open up the spectrum to new licenses by eliminating the EBS eligibility requirements and the educational use requirements for EBS licenses,
Bandwidth Capabilities	Mature EBS networks operated over 4G/LTE are observing customer bandwidth experiences of up to 25 Mbps down, 5 Mbps up.
Effective Distance	Effective distance is determined by the power of the device radio and the height of the cellular antenna array. Mounted antennas on subscriber homes support ranges of up to 9 miles, with shorter distances for mobile cellular antennas and lower tower arrays.
Scalability/Future Proof	Speeds currently being delivered would not meet future needs. As the FCC opens up this spectrum to new licenses and development, greater speeds may be achievable.
Typical Construction Costs Per Subscriber	Varies. Large scale EBS network operators must implement a cellular array per tower or community high point, Evolved Packet Core, tower study and tower lease costs, and customer premise antennas and/or device SIM cards.
Typical Operational Costs Per Subscriber	Current EBS networks operated by non-profit educational institutions are recovering costs of $15-$25 per subscriber per month.
Barriers	The FCC has not granted any new ITFS/EBS licenses since 1995. The July 2019 Report and Order will open up the spectrum to new license applications from tribal governments and commercial providers.
Possible Incentives	If the FCC would opt to allow E-rate support of Wi-Fi on buses, public/private partnerships of infrastructure deployment could make this 2.5GHz spectrum cost-effective for addressing a portion of the rural homework gap.
Pros	EBS operated over a mature 4G/LTE wireless network is a tried and true technology that can be easily managed.

Cons	The relatively high cost of equipment and tower deployment, coupled with the short range and modest bandwidths make this technology an unlikely contender for widespread implementation in sparse, rural areas.
Overall Feasibility	The feasibility of EBS for providers serving rural areas or for educational entities to address the homework gap depends upon the outcome of the FCC's current proceeding.

Fixed or Mobile Wireless—Citizens Broadband Radio Service (CBRS)

Description	Citizens Broadband Radio Service (CBRS), 3.5GHz (3550-3700 MHz), has been dubbed the “Innovation Band” by developers. The FCC made this additional spectrum available in 2015 as a result of the National Broadband Plan. Early development is aimed at LTE mobile wireless, fixed wireless, and Wi-Fi-like IOT implementations for venues and/or buildings. CBRS could also be used to replace last-mile fiber access, deliver fixed wireless services and point to multipoint service.
Bandwidth Capabilities	Potentially 1 Gbps indoors and 5-10 times higher outdoors with line-of-sight access. Midco, a cable provider in the northern plains states, reports offering speeds of 100/20 Mbps at distance of 8.8 miles using CBRS on an experimental license.
Effective Distance	Midco, a cable provider in the northern plains states, reports offering speeds of 100/20 Mbps at distance of 8.8 mile using CBRS on an experimental license. Charter Communications has also tested fixed wireless in the 3.5 GHz in rural communities, determining it can provide at least 25/3 Mbps at “significant distances.”
Scalability/Future Proof	Too early to tell.
Barriers	Development costs, and maturation of the spectrum usage and devices.
Possible Incentives	Newest spectrum made available by the FCC.
Pros	The CBRS band sits directly below and adjacent to the current NN Rural Broadband band of 3.65-3.70 GHz, making it easy for rural operators to adopt the new spectrum. The CBRS Band should significantly lower the costs of entry for non-traditional wireless carriers, and the propagation characteristics of the 3.5 GHz spectrum rivals current WiFi networks.
Cons	To use CBRS spectrum, one must request and be assigned a band by a Spectrum Allocation Server (SAS). The SAS calculates RF density and channel availability using terrain, radio propagation and current usage data before approving the request and allocating the spectrum.

Overall Feasibility	Too early to tell, but potentially promising.
Sources and Links	Testimony of Justin Forde to the Committee on Commerce, Science, and Transportation, Innovation, and the Internet, March 12, 2019 Mike Dano. Charter Hints at 25 Mbps fixed wireless speeds using 3.5 GHz in rural areas. (January 31, 2019). Fierce Wireless. Bob Brown. FAQ: What in the wireless world is CBRS? (March 14, 2014) Network World.

Mobile Wireless—4G/LTE

Description	4G LTE is the fourth generation of the mobile cellular network. It is the technology used by nearly all data-using mobile devices currently in service.
Bandwidth Capabilities	Theoretically up to 1 Gbps Practically up to 45 Mbps
Effective Distance	Several miles, up to 30-45 miles in flat terrain.
Scalability/Future Proof	Very scalable, currently available to ~90% of Americans. Still more room for growth in terms of speed and coverage area.
Barriers	Infrastructure development is expensive. Data caps and throttling reduce feasibility for use as primary broadband connection.
Pros	Widely used. All current mobile data technology revolves around 4G. Speeds are relatively fast, and nowhere near the potential upper limit.
Cons	Infrastructure development is expensive. If an area doesn't already have 4G, it likely means it is too expensive to cash flow. Terrain and vegetation can impact performance.
Overall Feasibility	4G is and will continue to be part of solving rural broadband issues.

Mobile Wireless—5G

Description	5G is the latest generation of wireless mobile communication.
Bandwidth Capabilities	Peak download speeds of 20 Gbps (theoretical) Expected user experience of ~1Gbps Increased antenna ports will increase the capacity of mobile networks by a factor of 22 or greater
Effective Distance	Very short. Small cells (miniature base stations) are required roughly every 250 meters. One estimate put it at one city block per cell.
Scalability/Future Proof	The millimeter wave technology that defines 5G and makes the increased speeds possible is impossible to spread over greater areas. It could be possible to build cells onto existing infrastructure, but .this would require significant coordination with utility companies and potentially create safety hazards.
Typical Construction Costs Per Subscriber	Unable to estimate. One estimate guessed that telecoms will spend $275 billion to roll out the technology over 7 years.
Typical Operational Costs Per Subscriber	Also unclear. AT&T has introduced a "5G" plan in some cities that only works at hotspots. Subscribers pay $70/mo for 15 gigabytes of data.
Barriers	High costs of deployment. Will not work with current mobile devices.
Pros	Very fast speeds. Universal support for development from major carriers and device manufacturers. Mobile network capacity will be vastly improved.
Cons	Distance limitations mean that covering large rural areas will be highly difficult. Current mobile devices will not work.
Overall Feasibility	While the technology could be used to handle traffic in home and office situations (and possibly farm yard networks), it seems nearly completely unfeasible to deliver broadband to rural Nebraska.
Sources and Links	Amy Nordrum, Kristen Clark and IEEE Spectrum Staff. (Jan. 27, 2017) Everything You Need to Know About 5G (Jan. 27, 2017) IEEE Ferry Grijpink, Alexandre Ménard, Halldor Sigurdsson, and Nemanja Vucevic. The Road to 5G: The inevitable growth of infrastructure cost. (February 2018). McKinsey. Aaron Pressman. AT&T Unveils Super-Fast Mobile 5G Service. Here's How Much It Costs. (Dec. 18, 2018). Fortune. http://fortune.com/2018/12/18/att-5g-price-mobile-hotspot/

Satellite—Geostationary Satellite

Description	HughesNet and Viasat have improved satellite service with Viasat advertising that it can provide up to 100 Mbps in select areas. The FCC's broadband map (with data as of June 2017) shows that service up 25 Mbps down and 3 Mbps up is available.
Bandwidth Capabilities	Advertised speeds up to 25 Mbps down and 3 Mbps up. 15 Mbps down 1 Mbps speeds are common.
Effective Distance	Available virtually anywhere in the U.S.
Scalability/Future Proof	Low Earth orbit satellites will likely replace current satellite service
Typical Operational Costs Per Subscriber	$69.99 per month for 20 GB/month at 25 Mbps down/3 Mbps up
Barriers	None
Pros	Available anywhere in Nebraska with a view of southern sky
Cons	Latency, data caps, and low upload speeds
Overall Feasibility	Latency and low upload speeds limit the use of some applications.

Satellite—Low Earth Orbit

Description	Several companies—including OneWeb, SpaceX, and Project Kuiper—are planning to launch low Earth orbit satellites to provide internet service. Deployment of satellite constellations may be far enough along to enable service as early as mid-2020. Latency may be as low as 25-35 milliseconds.
Bandwidth Capabilities	Up to 400 Mbps reported in OneWeb test
Effective Distance	Would be available anywhere
Scalability/Future Proof	Potentially scalable and future proof
Typical Construction Costs Per Subscriber	Customer equipment may be $500 or more.
Typical Operational Costs Per Subscriber	May be similar to pricing for geostationary satellite service but with higher speeds
Barriers	High cost of deploying satellite constellations Development of customer equipment
Possible Incentives	Undetermined
Pros	Would be available anywhere
Cons	Service may be limited to a certain number of subscribers within a geographic area.
Overall Feasibility	Potentially promising
Links	Jon Brodkin. OneWeb's low-Earth satellites hit 400Mpbs and 32ms latency in new test (July 17, 2019). ArsTechnica. Jon Porter. Amazon will launch thousands of satellites to provide internet around the world. (April 4, 2019). The Verge Caleb Henry. SpaceX launches 60 Starlink satellites, begins constellation buildout. (May 23, 2019). SpaceNews