An ad hoc performance comparison of candidate technologies for rural broadband deployment

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Abstract *– The need for network connectivity in rural and underserved areas is well known. An ad hoc comparison of data throughput for various broadband technologies is reported.*

Key Words: *broadband communications, rural setting, sensors, communications, analysis*

1. Introduction and Location

Broadband infrastructure is vitally important to rural and underserved communities, particularly as such regions have been coping with the COVID pandemic. Broadband can enable remote learning, telecommuting and telemedicine, and can be an engine for economic growth and talent recruitment, but existing infrastructure is inadequate for today's needs. All too often, families in such settings struggle with slow or unreliable service or have access to no service at all. And for families hit hardest by the pandemic, available services are often financially out of reach.

Addressing such a broadband challenge is important to individuals and organizations both as major regional employers and as a members of the community. The co-authors rely on a broadband infrastructure to execute their research and development (R&D) mission while many of our colleagues work remotely. Similarly, our families and friends rely on such a broadband infrastructure to adapt to the rapidly changing ways in which we now work, study and access healthcare services.

Different US federal entities have presented differing broadband download/upload speeds as being acceptable. For example, the US Federal Communications Commision (FCC) broadband benchmark is 25/3 Mbps, while the U.S. Department of Agriculture uses 10/1 Mbps [1]. Numerous organizations have stated that the minimum speeds should be higher than the 25/3 (and certainly the 10/1) values. In May 2022, the FCC proposed that the broadband up/down speeds should be asymmetric 100/20 Mbps [2]. Other groups are promoting symmetrical 100/100 Mbps speeds. Reference [2] presents a table of performance speeds for a variety of broadband technologies. Note that the sources referenced (below the table) are primarily vendor groups (with contested values).

Table 1. Fixed Broadband Upload and Download Speed Ranges by Broadband Technology

Broadband Technology	Download Speed Range	Upload Speed Range
Cable	10-500 Mbps	5-50 Mbps
Digital Subscriber Line	5-35 Mbps	1-10 Mbps
Fiber	250-1,000 Mbps	250-1,000 Mbps
Fixed Wireless	10-25 Mbps	1 Mbps
Satellite (Geostationary)	25 Mbps	3 Mbps
Satellite (Low-earth orbit)	100 Mbps	20 Mbps

Source: Tyler Cooper, *DSL vs Cable vs Fiber: Comparing Internet Options*, BroadbandNow, May 3, 2021, at https://broadbandnow.com/guides/dsl-vs-cable-vs-fiber;
HughesNet, *How Fast Is HughesNet Gen5?*, at https://www.hughesnet.com/get-started;
AT&T, *Fixed Wireless Internet*, at https://www.att.com/internet/fixed-wireless/;
R. Edward Price, *Petition of Starlink Services, LLC For Designation as an Eligible Telecommunications Carrier*, Space Exploration Technologies Corporation, February 3, 2021, p. 4, at https://ecfsapi.fcc.gov/file/1020316268311/Starlink%20Services%20LLC%20Application%20for%20ETC%20Designation.pdf.

Fig. 1. Technology speed comparison.

The activity presented in this manuscript involves an in-field Proof-of-Principal design and demonstration of potential communication system designs suitable for bringing rural broadband connectivity to an underserved

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area in East Tennessee[1]. The technology performance comparison demonstration project was designed and implemented to initially evaluate various topologies consisting of singular point-to-point, point-to-multipoint and satellite-based wireless communication technologies along with fiber optic , broadband over power line (BPL) and telephone (xDSL) technologies that are potential candidates for deployment in the region's varied topography. While noting that this is not a complete, comprehensive set of candidate technologies, a workshop involving the authors and individuals from numerous electric utilities acknowledged that no single network topology will be appropriate (or cost-effective) for this East Tennessee region. of technologies selected for the effort's first phase being a structured direct comparison demonstration of more than one topology through a designed - and scalable - testing scenario and system. The net result of the project being potentially leading to a design of a software tool tailored for determining the optimal communication basis, network topology and deployment strategy for topography and applications throughout the region.

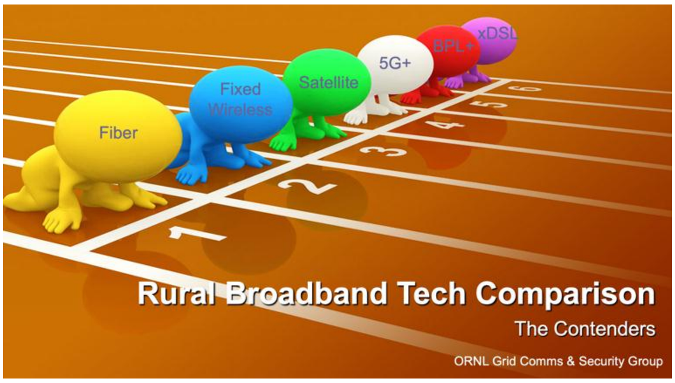


Fig. 2. Technologies assessed.

While an annual measurement and comparison of the performance of various broadband vendors has been conducted [3], that report focuses on comparing measured service versus advertised service. Meetings associated with "findings" and determining the content to be included in the report had participants from numerous possible broadband vendors and consortia proving content. Regardless, of industry consortia potential disagreements over content, the "target" speeds are based on the FCC's determination of light, medium, and high broadband usage - as shown in Figure 3.

	Light Use (Basic functions: email, browsing, basic video, VoIP, Internet radio)	Moderate Use (Basic functions plus *one* high-demand application: streaming HD video, multiparty video conferencing, online gaming, telecommuting)	High Use (Basic functions plus *more than one* high-demand application running at the same time)
1 user on 1 device	Basic	Basic	Medium
2 users or devices at a time	Basic	Medium	Medium/Advanced
3 users or devices at a time	Medium	Medium	Advanced
4 users or devices at a time	Medium	Advanced	Advanced

Basic Service = 3 to 8 Mbps*

Medium Service = 12 to 25 Mbps

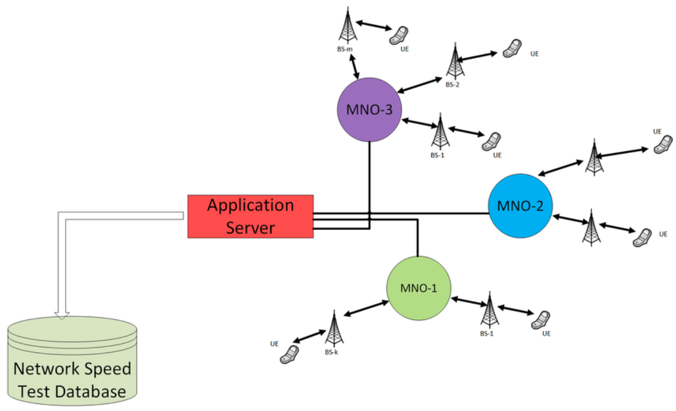
Advanced Service = More than 25 Mbps

*Mbps (Megabits per second) is the standard measure of broadband speed. It refers to the speed with which information packets are downloaded from, or uploaded to, the internet.

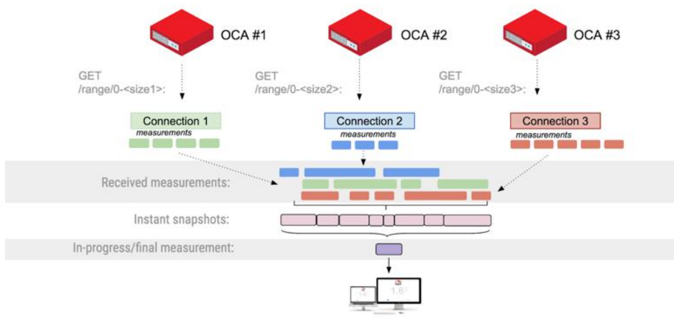
Fig. 3. Minimum acceptable download speeds - per FCC requirements. [3]

2. Controlled Setting Measurements

Basis network architectures for speed testing are presented in Figures 4.a and 4.b [4]. In each case it is apparent that the device or system under test is inserted ito the overall network topology with internet access. Multiple speed tests using fast.com as the point of network access were conducted.



(a)



(b)

Fig 4. Testing network configuration. [4, 5]

Note that the satellite speed tests were based on a Starlink system deployed in east Tennessee. That constellation involves numerous low earth orbiting satellites, therefore not suffering from the high latencies associated with geostationary satellite systems.

[1] with applicability worldwide.

Note that the results presented in this manuscript are not definitive, but rather comparative from a general perspective. While installation and testing of each technology has been optimized, a wide variety of system variables have not been fixed for each case. Restated, there are many operational parameters, such as differing "acceptable" bit error rates (BERs) for each technology deployment that may be adjusted when seeking maximum throughput speeds..

In addition, this comparison purposefully did not delve into the capital and operational expenditures that are associated with deployment and operation[2]. From an operational perspective, there are considerable differences between, say, buried and aerial deployed optical fiber communication systems. Again, this comparison did not take into account operational/maintenance activities associated with these two - or for that matter any - of the "technology contenders". The salient measured and compared performance parameter was data throughput speed[3].

Data throughput results are presented in Figures 5 and 6.

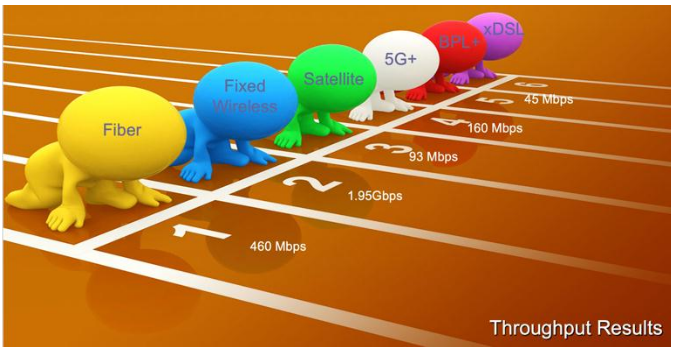
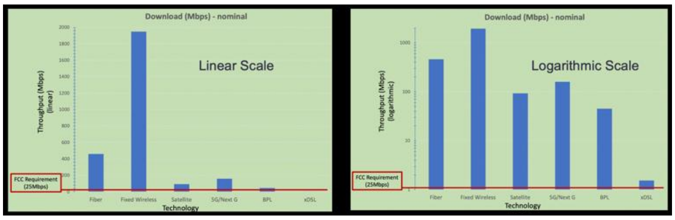


Fig. 5. Controlled setting "speed" measurements.



(a) (b)

Fig 6. Data throughput for the various "contenders" is shown on a linear scale (a) and logarthmic scale (b).

[2] Considerable information pertaining to broadband policies, technologies and operation are available in [6-15].

[3] Measured performance of bandwidth, latency, etc for a variety of internet service providers, ISPs, has been conducted by the US Federal Communications Commission (FCC). Results from a 2018 study "Measuring Fixed Broadband - Eighth Report", are available at https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-eighth-report

3. Field Measurements

Utilities have expressed an interest in providing broadband service to their customers. In many cases, the utilities' service area is a rural setting with - in the case of east Tennessee - a rolling topography. Given the laboratory-based speedtest results, it was decided that in-field performance tests and demonstration should be undertaken.

Each of the technologies listed in Figure 2 were chosen for performance demonstration in Lenoir City Tennessee. The scenarios are shown in Figure 7.

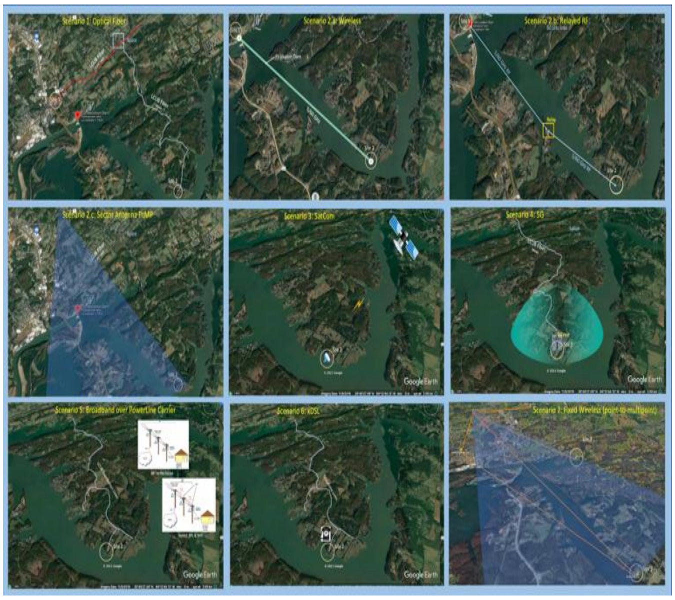


Fig. 7. The envisioned scenarios for rural broadband technology deployment in Lenoir City TN USA.

3.A. (Site A) - Agricultural Science Center (ASC), Lenoir City TN USA

The twenty hectare Agricutural Science Center (ASC) was selected as the in-field site. A combination fixed wireless plus satellite-based network was designed and deployed. Specifically, a Starlink satellite system was deployed along with a 5G network interface, a 60 GHz point-to-point transceiver system (with high gain parabolic antennas), 802.11ac and Wi-Fi6 transceivers with omnidirectional antennas, Wi-Fi enabled video cameras and sensor modules. An approximation as to where the components are deployed is presented as Figure 8.

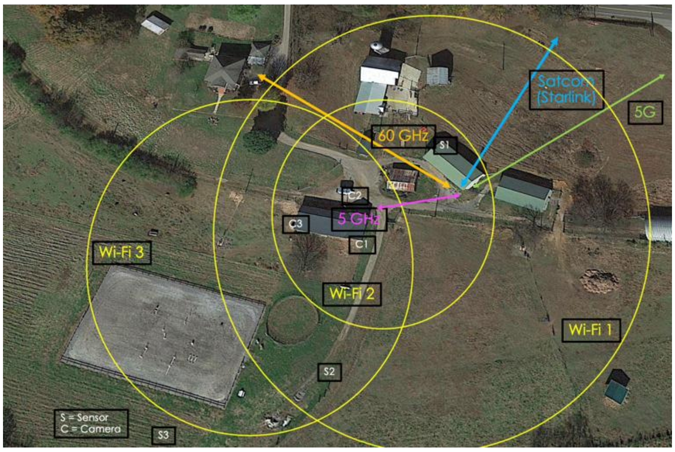


Fig. 8. Locations of deployed system components.

The Site A network topology - component connectivity - is presented as Figure 9. The elements listed as "birdhouse1" and "ESP_A8F8EA" are independent sensor suites measuring outdoor setting ambient conditions. Remote access to the network relies on the Starlink satellite and an established Virtual Private Network (VPN) for secure connectivity.

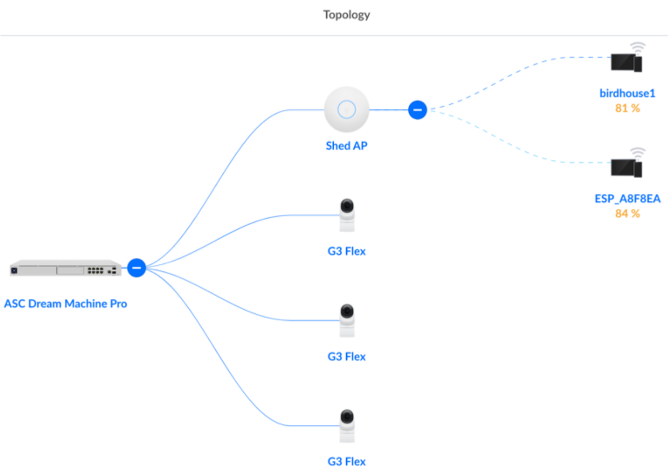


Fig. 9. Site A's device list and network topology

3.B. (Site B) - Tower Mounted at Lenoir City Utility Board (LCUB) Lenoir City TN USA

As a proof of concept, a network similar to that deployed at Site A was designed for installation using towers and facilities owned and maintained by the Lenoir City Utility Board (LCUB). Given the rolling, tree-laden terrain in the town (and surrounding area) of Lenoir City, the design relied on internet connectivity at the LCUB headquarters building followed by a dual 5/60 GHz transceiver link to companion transceivers mounted on a 85m tall utility tower. As shown in Figure 10, drones were used to "oversee" the tower climbing crews' installation and alignment of the transceivers.

Fig. 10. UAS (drone) being used to confirm antenna alignment on Site B's radio towers (~85m height).

A point-to-multipoint 45⁰ field-of-view sector antenna was installed on the tower for "local" internet connectivity as well as a 60 GHz parabolic antenna (which was pointed at the Fort Loudon hydroelectric dam). The Site B network topology is presented as Figure 11.

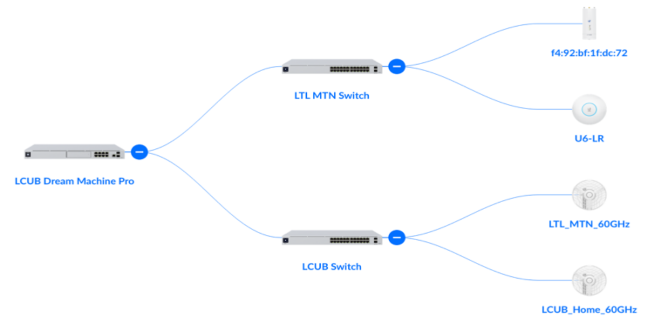


Fig. 11. Site B's device list and network topology..

Understanding that this component of the proof-of-concept effort was to serve as a use case for other regional utilities to understand this fixed wireless broadband deployment, the sector antenna was pointed in the direction of the center of the town. An approximation of the antenna's radiation pattern (RF footprint) is shown in Figure 12.

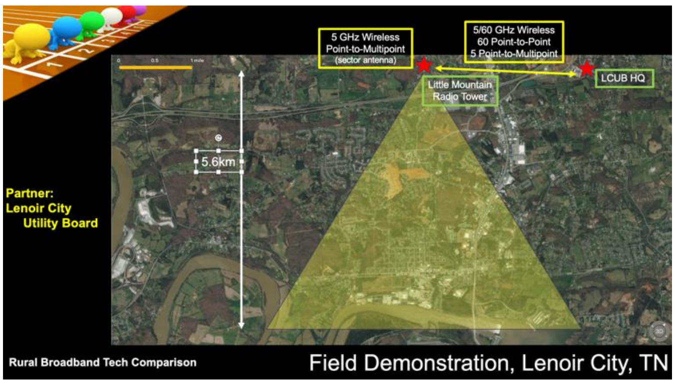


Fig. 12. Layout and estimated signal coverage for Lenoir City field tests.

The internet connectivity originated at the LCUB Headquarters - see Figure 13 - with a data throughput at that site being 26 Mbps. In-field, around town, measurements of data throughput were conducted using a Cassegrain-design 35dBi gain antenna which was connected to a laptop computer. Representative throughput measurements are shown in Figure 13.

Fig. 13. In-field data throughput measurements for the PtMP configuration.

Data throughput was 92% of the throughput at the source. Measurements were taken at a distance of 4km from the Little Mountain tower.

4. Summary

An ad hoc comparison of a number of technologies that are candidates for delivering broadband to rural and underserved areas was undertaken. It is key to note that the financial and logistical aspects associated with each technology were not compared. After the controlled setting measurements were completed, an in-field demonstration was undertaken in a small town setting in east Tennessee. It is envisioned that the next steps in investigating varying technologies for possible delivery of broadband services will involve continued testing of the fixed wireless and hybrid systems in the region's varying topography, illustrated in Figure 14.

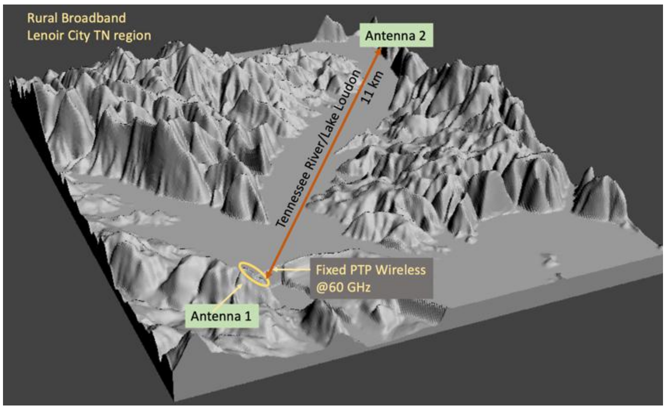


Fig 14. Demonstration site, Lenoir City Tennessee USA, has varied topography.

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