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Evaluating the Capabilities of Fixed Wireless Technology to Deliver Gigabit Performance in Rural Markets

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Introduction and Summary

The current pandemic has accelerated the profound impact that the Internet is having on nearly every area of our lives, including education, retail, healthcare, public safety, and entertainment. The Internet continues to transform how we communicate, the size and scope of our global economy, and even our political system. We are on the cusp of the next Internet evolution – the Internet of Things (IoT). Over the next 10 years, the Internet will evolve into a network that overwhelmingly connects "things" rather than people. Customers will continue to demand faster speeds and higher capacities as telehealth becomes more commonplace as a means of medical care, as education increasingly migrates online, as Ultra High-Definition television (UHDTV) becomes commonplace, and with the dramatic growth of connected devices of all kinds needing Internet access.

The Federal Communications Commission's (FCC) Tenth Measuring Broadband America Report[1] shows that the average speed was determined to be 146.1 Mbps in October 2019. This speed has increased by an average of 54% annually since the FCC's Eighth Report just two years ago.[2] Over the past four MBA reports, the average annual increase has been over 35% in both the download and upload speeds. At this rate, the average broadband download speed will exceed 1 Gbps within the next 6 years as shown in Figure 1. In January of 2019, NCTA-The Internet & Television Association claimed that 80% of all households can currently order gigabit service.[3] This is largely because over 80% of the United State population is urban.[4] However, the FCC believes there are 23.1 million Americans that cannot receive the FCC's currently-defined minimum broadband standard of 25 Mbps down and 3 Mbps up.[5] The researchers at Broadband Now believe this number could be as high as 42 million.[6] Whatever the precise number, it is clear that millions of Americans have been stuck on the wrong side of the digital divide despite a decade of programs intended to reach them, which makes it all the more important that new funding programs verify that recipients will deliver the services promised for these users.

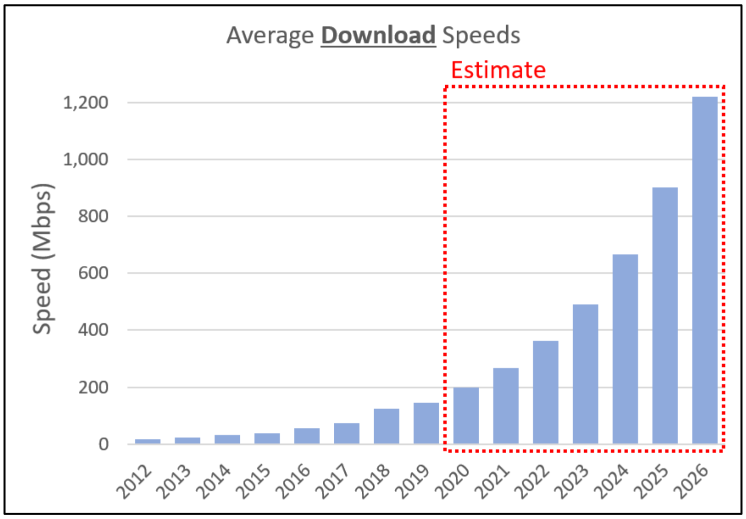

Figure 1. Average Upload Speeds – Based on FCC MBA Reports

[1] FCC's Tenth Measuring Broadband America (MBA), Fixed Broadband Report, January 4, 2021.
[2] Ibid, page 7.
[3] https://www.ncta.com/whats-new/america-is-now-a-gigabit-nation#.X_vnzVAGcIc.link
[4] https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/ua-facts.html
[5] FCC's 2019 Broadband Deployment Report, May 29, 2019.
[6] https://broadbandnow.com/research/fcc-underestimates-unserved-by-50-percent

The FCC should be applauded for recognizing the trend toward higher speed broadband services and developing a weighting system that favored the networks that have higher speeds and greater capacity in the Rural Digital Opportunity Fund (RDOF) auction (FCC Auction 904). On its face, the auction could be seen as an overwhelming success, since more than 85% of the locations awarded were awarded at gigabit speeds. However, as the layers are peeled back and the technical underpinnings of varying proposals are analyzed, there is substantial question as to whether these speeds will actually be delivered in some cases and applications.

As one example of such analysis, this paper considers specifically the extent to which fixed wireless services may be capable of delivering Gigabit-level services in the kinds of sparsely populated rural areas that the RDOF auction primarily seeks to serve. Most of the RDOF winners that were successful at the Gigabit tier[7] proposed using Fiber to the Premises (FTTP) technology – although many of them left the door open to use fixed wireless services. Others appear to have contemplated using, and received permission to bid using, fixed wireless technology specifically to deliver Gigabit level services. While current FCC Form 477 data (among many other resources) confirms that FTTP networks have been delivering gigabit services to urban and rural customers for many years, there is no comparable track record with respect to fixed wireless technologies. This makes it all the more important to take a careful look, based upon objective engineering criteria, at whether and to what degree fixed wireless networks can deliver Gigabit level services – especially in rural areas where serviceable locations can be several hundred feet to miles apart. This paper concludes that there are significant technical (and related economic) questions that must be confronted in delivering Gigabit broadband using fixed wireless technologies in the predominantly rural areas covered by RDOF and the FCC therefore needs to perform a careful analysis pursuant to objective and well-accepted technical engineering criteria during the long-form process prior to approving such claims of capability.

More specifically, as explained further herein, engineering analysis by reference to objective technical standards indicates that fixed wireless networks will face difficult, if not insurmountable, challenges to provide RDOF Gigabit services[8] in very select circumstances when attempting to service distant, non-town rural subscribers that were primarily the subject of the RDOF auction. U.S. Senators John Thune (R-S.D.) and Amy Klobuchar (D-Minn.), as well as 46 of their Senate colleagues, have previously highlighted the need for such analysis in a Letter to Chairman Ajit Pai, whereby they observed that, "If a party is incapable of delivering broadband as promised, the American ratepayer loses twice over – first for having contributed sums that did not go toward the deployment of broadband as hoped, and then again as those ratepayers who reside in the area that ended up not receiving the promised service……It is important for the FCC to be responsible for USF resources and ensure that those parties receiving support can deliver on the commitments they make."[9]

During the review of the long form applications, we believe it essential for the FCC to consider technical and related economic criteria such as those analyzed herein to determine whether and to what degree each applicant

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[7] For RDOF purposes, a Gigabit service is 1,000 Mbps downstream and 500 Mbps upstream (RDOF Gigabit-Level Service).

[8] *See* FCC 19-104, Order on Reconsideration - FCC Takes Steps to Enforce Quality Standards for Rural Broadband, adopted October 25, 2019, available at https://www.fcc.gov/document/fcc-takes-steps-enforce-quality-standards-rural-broadband, ("FCC Quality Standards Order on Reconsideration"), on the Order, DA 18-710, WC Docket 10-90, adopted July 6, 2018, available at https://docs.fcc.gov/public/attachments/DA-18-710A1.pdf, ("FCC Quality Standards Order"). ¶ 51 of the Order states: "For speed, we require that 80 percent of download and upload measurements be at or above 80 percent of the CAF-required speed tier (i.e., an 80/80 standard)."

[9] Thune/Klobuchar RDOF Senate Letter of December 9, 2019 to Chairman Pai, available at https://www.thune.senate.gov/public/_cache/files/ec9ab287-8920-4353-b46e-1396ccdf103e/F68789196918856CBDF441B3B801C99E.rdof-letter-12.9.19.pdf, ("Thune/Klobuchar RDOF Senate Letter"), p. 1.

will be capable of delivering Gigabit level service based upon its proposed network design. When considering any proposed wireless network designed based on **mid band spectrum**, it would be difficult or impossible to conceive a scenario where a wireless network in this band could reliably provide RDOF Gigabit-Level Services. The only band that would have enough capacity to accommodate even just a small handful of gigabit users would be the 5 & 6 GHz unlicensed bands. When using these bands, the wireless provider is not protected from interference from other wireless users and devices such as common home Wi-Fi routers. This is not an acceptable solution, especially when considering the RDOF broadband services must also provide voice services and access to emergency services such as 911.

Meanwhile, when considering any proposed wireless network designs based on **millimeter wave (mmW) technologies** for any RDOF bidder to satisfy their Gigabit service commitment, the FCC should verify the following:

1. All customers must be within about 500 feet of their specific serving tower/antenna.
2. All customers must have clear line-of-sight to that serving tower/antenna.
3. The capacity of the serving tower/antenna or sector must be adequate to accommodate the downstream and upstream capacities of all users served by that antenna or tower.
    a. The RDOF 70% subscription requirement must be considered in analyzing the capacity of the service tower/antenna or sector.
    b. A reasonable oversubscription ratio on the order of 4:1 or less should be applied.
4. Each antenna and/or sector must also have adequate backhaul capacity to accommodate the number of RDOF customers anticipated with a reasonable oversubscription ratio such as 4:1. In most instances this will require the towers/antennas to be served with a fiber network.
5. When considering mmW mesh networks, in addition to the preceding factors, the FCC should also evaluate the congestion that would occur between the nodes of the mesh network as well as the potential radio frequency congestion and the backhaul congestion.

Gigabit Broadband and RDOF

When considering the most effective and efficient use of resources for broadband network investment, it is necessary to understand current and future user demands to ensure the planned network can meet these increasing demands over its economic life. In addition to cost, performance factors such as speed, latency, capacity, and reliability are of course important factors. Some networks may have lower initial cost but be less reliable and less scalable to meet future customer demands or have higher operational expenses. Some technologies meanwhile may not be able to meet certain performance levels altogether – or maybe only under limited or ideal circumstances. Such is the case for those proposing to use wireless technologies to meet the gigabit speed tier in the kinds of rural areas subject to the RDOF auction.

The FCC has defined the gigabit speed tier for purposes of the RDOF auction as 1 Gbps downstream and 500 Mbps upstream with 2 TB of monthly usage allowance (defined hereafter for purposes of this paper as "RDOF-Level Gigabit Service").[10] From a network engineering perspective, the only logical interpretation of this requirement is that the end user should be able to simultaneously use 1 Gbps in the downstream direction and 500 Mbps in the upstream direction. The Wireless Internet Service Providers Association (WISPA), however, appears to believe that Gigabit service could be half-duplex (meaning it would be acceptable to limit customer use by permitting communication in only one direction at a time at full capacity).[11] In this scenario, only 1 Gbps of total network capacity would be needed to serve this end user, since one would assume that the same capacity could be used for the upstream as with the downstream. Considering the large number of users and devices in a home today that are actively using the Internet and the FCC's desire for broadband services that will meet and keep pace with user demand, we presume that the FCC's intent was not to approve "one way at a time" service and limit use to "upstream or downstream only" and that the channel should therefore have an aggregate throughput of 1,500 Mbps (upstream plus downstream), which would allow the required capacity to be utilized in both directions at the same time.

All successful bidders in the RDOF gigabit tier must provide RDOF-Level Gigabit Service to all customers in the awarded census blocks within 6 years.[12] While this time frame is necessary to accommodate construction, it means that the FCC, affected customers, and other stakeholders may not know whether RDOF-Level Gigabit Service will actually be delivered as promised for years to come. By the time it is apparent that an RDOF recipient cannot meet its FCC commitments, these customers – already languishing in unserved areas – will be left behind once again, and it may very well be too late to include these areas in a second phase of the RDOF auctions. Because of this, it is important for the FCC to ensure, prior to distributing funds (or ideally prior to even making awards), that every RDOF awardee, regardless of technology choice, has a reasonable chance of success based upon its technical and operational capabilities evaluated against a backdrop of objective engineering criteria.

The FCC conducted only a limited review of the technology during the short-form process because it did not have "more information about exactly where the applicant will win support and how many locations it will serve."[13] At

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[10] In the Matter of Rural Digital Opportunity Fund, WC Docket No. 19-126, Released Feb. 7, 2020 ("RDOF Order"), ¶ 31.

[11] In an June 2, 2020 Ex Parte entitled, "Rural Digital Opportunity Fund, AU Docket No. 20-34, WC Docket No. 19-126, WC Docket 10-90, Notice of Ex Parte Presentations," WISPA argues in response to technical concerns raised by one of its most prominent members, "First, GeoLinks suggests that 1 Gbps/500 Mbps service needs at least 1500 Mbps aggregate throughput. That assumes simultaneous or inflexible uploading and downloading."

[12] RDOF Order, ¶ 45.

[13] Rural Digital Opportunity Fund Phase I auction Scheduled for October 29, 2020, Notice and Filing Requirements and Other Procedures for Auction 904, June 11, 2020 ("RDOF Auction Procedures Order"), ¶ 125.

the same time, the FCC's own data indicate whether and to what degree certain technologies are and are not being used to deliver certain tiers of service today in varying kinds of rural and urban applications. Indeed, WISPA argued that "The record also indicates that equipment that may support RDOF Gigabit speeds under certain conditions has since been developed and is being commercially deployed today."[14] This statement may be true (subject to the conditions and contingencies contained within it), but even just a cursory examination confirms that the "certain conditions" to which WISPA referred that "may" permit fixed wireless service to deliver gigabit speeds rarely exist when considering residential broadband deployments in the kinds of rural areas included in the RDOF auction. This makes it all the more important that the FCC only award RDOF support where an objective review against published and well-accepted standards of conditions on the ground confirms that there is a reasonable expectation of meeting the RDOF requirements based on the technology proposed.

The FCC should therefore continue its policy of awarding RDOF areas only to those that can be "reasonably expected to be capable of meeting the relevant public interest obligations."[15] Using this as a standard and based upon a review of commonly accepted engineering standards, we conclude in this paper that fixed wireless technologies will face serious challenges at best to deliver RDOF-Level Gigabit Service in the kinds of areas subject to the RDOF auction. At the very least, the FCC should utilize published criteria and analyses like those employed herein to review the long form applications and ultimately articulate in detail why it believes any given auction winner will be capable of delivering RDOF-Level Gigabit Service using fixed wireless technologies given what the standards otherwise indicate.

The Wireless Sandbox

Immutable laws of physics permit only three primary ways to improve wireless throughput. This can be done by 1) improving the signal-to-interference-plus-noise ratio; 2) improving the efficiency of the spectrum by using higher order modulation and coding techniques which can be leveraged when the signal is strong and largely free of noise and interference; or 3) increasing the amount of spectrum available to a customer through adding more spectrum, segmentation (cell splitting), or using sophisticated and expensive techniques such as high-order multi-input multi-output (MIMO) and/or beamforming.

All wireless providers share the frequency spectrum or "airwaves" with many other wireless providers – even some that may be operating in the same frequency band. In addition, all wireless spectrum transmitted from a given antenna or sector is "shared" amongst all customers served by that sector. Because of this, there are strict rules that govern how the wireless operator can use this spectrum. Some of the rules include:

- **Frequency Band** – A wireless operator is authorized to operate in specific frequency bands. These frequency bands may be licensed ("licensed spectrum") to this operator for their sole use within a defined area or the spectrum may be unlicensed ("unlicensed spectrum") which is shared by many users or devices. More recently, the FCC has allowed the use of "lightly licensed spectrum" which can be shared by many users in a more controlled environment where each provider must coordinate their use of the spectrum with others using the same spectrum.

[14] WISPA Ex Parte titled, "Rural Digital Opportunity Fund, AU Docket No. 20-34, WC Docket No. 19-126, WC Docket 10-90, Notice of Ex Parte Presentations," June 2, 2020.

[15] Comment Sought on Competitive Bidding Procedures and Certain Program Requirements For The Rural Digital Opportunity Fund Auction, Released March 2, 2020, ¶ 53.

- **Radiated Power** – The maximum transmit power allowed is also controlled by federal regulation. The radiated power must be closely controlled to allow the wireless provider enough power to provide service to a customer, but not so much to interfere with another provider that may be operating in an adjacent area. Generally, higher powers are allowed when operating in licensed spectrum rather than unlicensed spectrum. Higher transmit powers generally increase the signal-to-noise ratio (SNR) of the radio frequency signal, which allows faster throughput, but may also cause the signal to continue propagating into neighboring areas causing interference that pollutes the desired signal in these areas and impairs the throughput other customers.
- **Modulation and Other Factors** – The type of modulation, coding, and other factors are also often governed and controlled by the FCC or other standards bodies.

The importance of both wireless spectrum and radiated power of a wireless system can be understood with a simple analogy. If we assume the transmit power of the wireless system is like the water pressure in a garden hose (i.e., the higher the water pressure, the farther the stream at the end of the hose) then the wireless frequency spectrum would be like the diameter of the hose. In order to deliver more water (similar to more speed in a wireless system), one can either increase the water pressure or increase the size of the hose. Since the FCC closely regulates the amount of radiated power (water pressure) then the next logical thing to consider for increasing wireless speed and throughput is to increase the amount of spectrum (size of the hose).

To enable wireless providers to offer faster broadband, the FCC has been aggressively making more spectrum available for broadband use. New technologies, such as beamforming, higher-order MIMO, and higher order modulation and coding techniques have helped providers use the spectrum more efficiently. Nonetheless, despite the infusion of additional spectrum capacity into the broadband marketplace and more sophisticated techniques, the physics of radio wave propagation is always a limiting factor to realizing a solid connection, much less an advanced connection capable of delivering higher performance, especially in rural areas with trees, hills and customers thinly spread out – like those in the RDOF auction.

Wireless Network Design Considerations

As mentioned previously, wireless networks transmit their signals over airwaves that are shared by many providers and users. There is a fixed and finite amount of network capacity for the users sharing the same spectrum, so as more users demand more capacity, data on the network will travel slower for each user. Most have experienced slower Internet on their wireless devices when in a crowded city or at a large-scale event like a concert where many people are trying to use the wireless network in that area at the same time. In simple terms, the wireless signal from an antenna or “beam” is used by all users served by this antenna, such that the wireless capacity is necessarily divided amongst all these users and leaving less capacity for any one user than would otherwise be the case.

The importance of oversubscription to wireless network design (or the design of any network with elements of shared capacity, for that matter) cannot be overstated. Understanding the concept of oversubscription is essential to understand the actual broadband capability of a wireless network. If there are 20 users sharing an antenna, and each user has subscribed to 100 Mbps service, even as simple math would indicate the potential for 2 Gbps of capacity use (20 * 100 Mbps), it is unnecessary to design the system for that level of capacity because experience confirms that not all users will typically require their full speed at the same time. To account for this, network engineers use the concept of "oversubscription." In essence, oversubscription defines how many times you "resell" the same network capacity where it is shared among multiple users of that network. Over the last 20 years, acceptable oversubscription ratios have been declining as network traffic migrates from its once "bursty" nature of short web browser sessions to more continuous applications like video. Today, it is not uncommon to design a wireless network with an oversubscription ratio of 4:1 or less. Applying an oversubscription ratio of 4:1 to the example above, only 500 Mbps of capacity rather than 2 Gbps would be needed (in that antenna or sector) to serve the 20 customers (each subscribed to a 100 Mbps broadband package). When fewer customers share the same antenna resources it is less likely that customers will experience problems from spectrum sharing.

To increase the wireless speed and capacity that can be offered to their customers, wireless operators often try to reduce the number of customers served by an antenna (or sector or beam). This is often done by increasing the number of towers serving a given area which is often referred to as "network densification." Network densification in rural areas can reach a point of diminishing returns, however, since the transmitted power from tower manifests itself as noise and interference in a neighboring area serviced by a different tower. To help minimize the interference in the neighboring areas, the power must be reduced, the antenna height reduced, or additional downtilts applied to the antennas. Reducing the power often results in decreased speed and signal quality. Reducing the antenna height may put the signal at the mercy of obstacles found in rural areas such as hilly terrain, trees, buildings, or other obstacles, which most likely will block the signal altogether or, at a minimum, decreases speed and signal quality. This means that any effective wireless network design in a rural area must take careful account of the trade-offs between power, potential for interference, antenna height, and topography.

Three basic architectures are used in wireless network design. These are Point-to-Point (PtP), Point-to-Multipoint (PtMP), and mesh. PtP systems are generally used for applications such as wireless backhaul or connecting two buildings together. They often rely on directional antenna on each end to focus the signal and typically consist of more expensive equipment. Because of the focused beam, they can often achieve longer distances than PtMP systems. PtP systems are not generally used for residential broadband, however, since each user would require its own dedicated antenna on the central tower, which is impractical for technical and economic reasons. Residential wireless broadband is therefore most often provided using PtMP systems (a signal antenna at a central site that serves multiple end user terminals) and occasionally mesh systems.

Mesh systems can often extend the reach of a wireless network since each "node" on the mesh network acts as a relay point to extend the signal before the next wireless "hop." This can provide benefits, especially when operating in the mmW bands where the distance is very limited and there is a need for the intermediate mesh nodes to boost the signal for the more distant users. These mesh nodes are often placed on rooftops of houses in a neighborhood. Since mmW cannot penetrate objects (trees, buildings, etc.), if you cannot see your neighbor's roof from your roof, then neither can a mmW signal "see" the next node. There may be some instances where the neighbor's roof is visible, most rural locations are not within sight of other locations – being out of sight of neighbor is, in fact, a bragging point for many rural citizens.

In the instances where a mesh network could gain some distance, the overall network capacity suffers since each node on the mesh must not only carry the capacity of the user which it serves, but also all the other users that are transmitting their signals though that node. When the capacity for several users is aggregated through a signal mesh node, the speed of each user is reduced. Those customers closest to the fiber backhaul connection point could possibly achieve the desired speeds, but the customers added farther out on this "daisy chain" to meet buildout requirements, could experience degraded service as the links between the mesh nodes become congested. Another downfall of mesh is that they rely on continued support of mesh nodes at neighboring locations. Situations and sentiments change about technology and neighbors may come and go. A new occupant may want nothing to do with the mesh node on their roof and can instantly cripple multiple end users downstream by removing it.

It is against this backdrop that we can review the conditions under which it may or may not be practical to deliver RDOF-Level Gigabit Service using a wireless network.

Delivering Gigabit Service over Wireless

Since an adequate amount of spectrum is critical to deliver gigabit services to end user customers and the wireless spectrum is highly regulated, we must first determine if an entity proposing to deliver RDOF-Level Gigabit Service via a fixed wireless solution has access to adequate spectrum to do so. Without the needed spectrum, its efforts will be futile.

How Much Spectrum is Needed?

When considering the amount of wireless spectrum needed, one must consider both the upstream and downstream needs. For RDOF Gigabit-Level Services, this is 1 Gbps downstream and 500 Mbps downstream. This would mean that the wireless channel would need to support 1.5 Gbps for a single user. Since the network will need to be designed to support more than one user, the sector or antenna capacity would need to be greater. If we assume, for example, that a provider would need to support a modest 8 users at the RDOF Gigabit level with a 4:1 oversubscription ratio,[16] then the sector or antenna would need to support 3.0 Gbps (1.5 Gbps x 8 / 4). This is 3.0 Gbps of actual throughout, not "Over the Air" (OTA) capacity as often quoted on vendor datasheets. Actual throughput is much lower than OTA throughput as will be discussed later.

The broadband speed that a frequency band is capable of is often referred to in terms of "spectral efficiency." Spectral efficiency is measured in "bits per second per hertz" (bps/Hz). A wireless system with an average spectral efficiency of 2 bps/Hz would be capable of delivering 20 Mbps, on average, to an end user in 10 MHz of spectrum (10MHz * 2 bps/Hz = 20 Mbps).

The most advanced MIMO techniques enable modern wireless networks to achieve an average of 2 to 4 bps/Hz across their coverage areas. Giving the wireless system the benefit of the doubt and assuming that the deployed wireless system could achieve a spectral efficiency of 5 bps/Hz, a provider would need 300 MHz of spectrum for a single user and approximately 600 MHz for 8 users with a 4:1 oversubscription ratio. The challenge then becomes finding 600 MHz of spectrum to use. (It is also worth noting how highly conservative these assumptions are; to support twice this number of customers, for example, approximately twice this amount of spectrum would be required.)

Available Wireless Spectrum for Gigabit Services

There are three general areas of spectrum are used to deliver wireless broadband services. These are the low band, mid band, and high band (often referred to as the mmW band). The spectrum available for broadband in the low band is so limited that it would not be possible to deliver RDOF Gigabit-Level Services, so we will focus

[16] Preseem's "Fixed Wireless Network Report", Fall 2020 Edition shows that approximately 75% of all WISP networks employ an oversubscription ratio of 4:1 or lower.

only on the mid band and mmW bands. The portion of the mid band of interest here ranges from 2 to 6 GHz and the portion of the mmW frequencies range from approximately 30 to 80 GHz.

The frequency bands that can be used for broadband can be seen in Table 1. The FCC has made a variety frequency bands in the mid band available over the years and is taking significant steps to make more available. However, as can be seen in Table 1, the broadband operator may be the secondary user of the spectrum (such as CBRS and C-Band) or is unlicensed which is shared with many other users and devices (such as the U-NNI band). The broadband provider also rarely has access to the entire spectrum in the band and often must operate in smaller blocks of spectrum within that band (shown in the "Allocation" column). As we will see later, this presents challenges when attempting to use mid band spectrum for high-capacity broadband services.

Band Name	Frequency	Total Spectrum	Allocation	How Licensed
Low Band Spectrum				
600 MHz	600 MHz	70 MHz	2x5MHz Blocks	Licensed
700 MHz	700 MHz	104 MHz	2x[1, 5, 6, or 11] MHz Blocks	Licensed
Mid Band Spectrum				
WCS	2.3 GHz	30 MHz	2x5MHz Blocks	Licensed
ISM	2.4 GHz	85 MHz	10, 20, or 40MHz Blocks	Unlicensed
BRS/EBS	2.5 GHz	190 MHz	6, 16.5, 49.5, 50.5MHz Blocks	Licensed
CBRS (secondary use)	3.5 GHz	150 MHz	10MHz Blocks (PAL)	Lightly Licensed
C-Band (secondary use)	3.7 GHz	280 MHz	20MHz Blocks	Licensed
U-NII	5 & 6 GHz	1,525 MHz	10, 20, 40, or 80MHz Blocks	Unlicensed
mmW Spectrum				
UMFUS – Auction 101	28 GHz	850 MHz	425MHz Blocks	Licensed
UMFUS – Auction 102 (secondary use)	24 GHz	700 MHz	2x40MHz Blocks	Licensed
UMFUS – Auction 103	37/38/47 GHz	3,400 MHz	100MHz Blocks	Licensed
V-Band	60 GHz	5,000 MHz	2160MHz Blocks	Unlicensed

Table 1 – Portion of Radio Spectrum Available for Broadband

Figure 2 graphically shows the relative amount of available spectrum in the various bands. The pie sections in Figure 2 are to scale and include all the available spectrum in that band. In most instances a single provider would have access only to a relatively small portion of the larger band. Frequencies in the mid band were generally allocated to providers as small channels. While some providers may have several of these channels in the mid band for a given geographical area, they are not always contiguous in the frequency spectrum which makes it more difficult or even impractical to combine the channels for achieve higher throughputs.

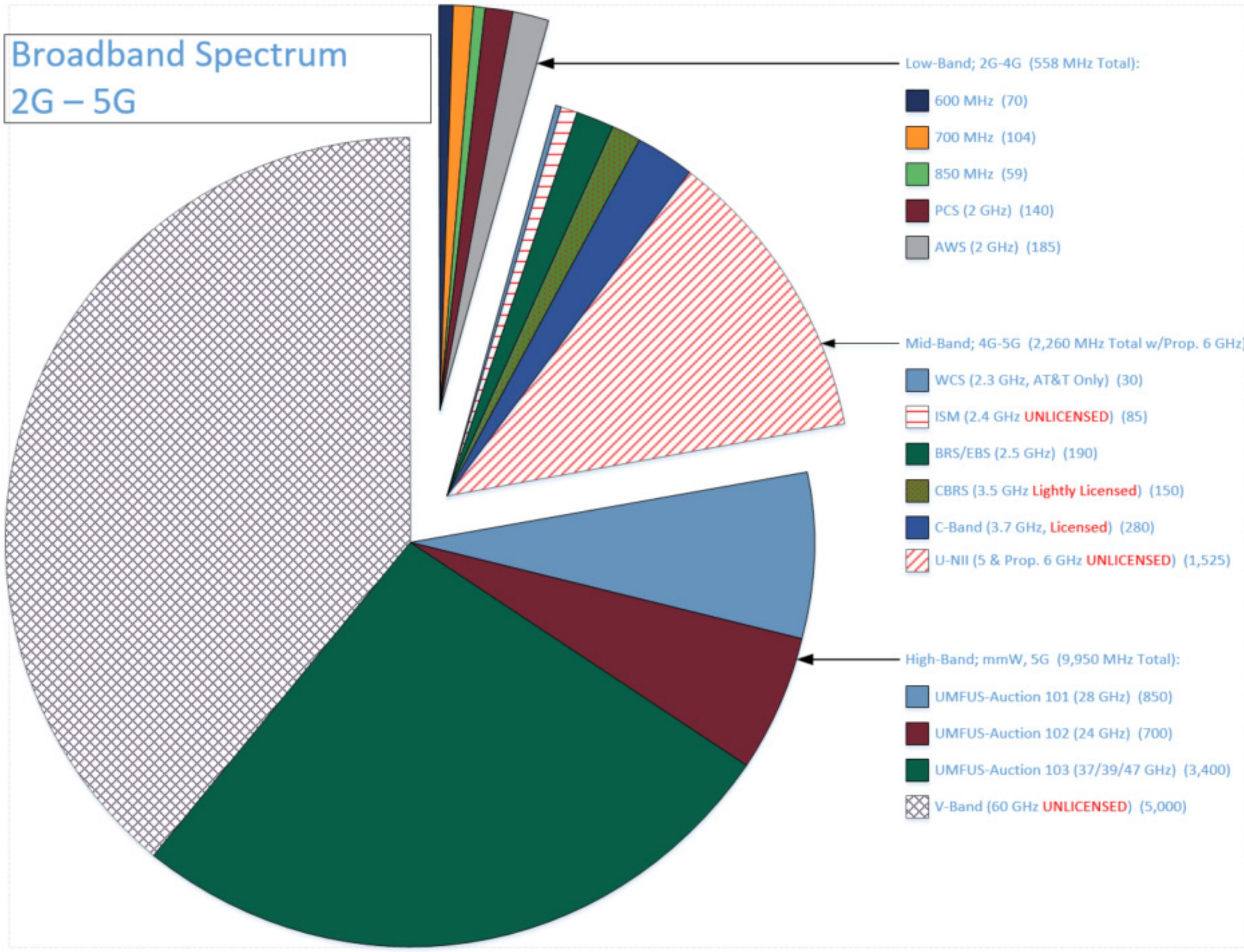

Figure 2. Broadband Spectrum

RDOF Gigabit-Level Services Using Mid Band Spectrum

In the conservative examples discussed earlier, one would need at least 300 MHz (single wireless customer), but more likely 600 MHz or more, to serve a small handful of customers with RDOF Gigabit-Level Service. It would be difficult to find that much frequency in the mid band that would have enough spectrum available for a broadband provider to deliver RDOF Gigabit-Level Services to even a modest number of customers. The only band with possibly enough spectrum would be the 5.8 GHz and proposed 6 GHz bands which are expected to have 1,525 MHz available. But even if these bands might offer enough capacity to deliver RDOF Gigabit-Level Services to a confined number of customers, they present other challenges – these bands are unlicensed and thus shared with others with no interference protection, including nearly all common Wi-Fi routers. When considering options to satisfy the RDOF requirements, sound engineering principles must be applied along with equipment that can be deployed in a cost-effective and practical manner. This widespread shared unlicensed use would make it impractical for a provider to deliver RDOF-Level Gigabit Services on a consistent basis. The 5.8 and 6 GHz bands are part of the Unlicensed National Information Infrastructure (U-NII) service where higher power is permitted for

PtP[17] networks, but these require large parabolic dishes (or equivalent antennas) at both ends to provide service farther than a few kilometers. However, these antennas and power levels are not available to PtMP operations, which would be needed to serve residential customers in rural areas, and large-scale use of point-to-point for point-to-multipoint applications would be absurd. Costs of employing PtP or PtMP networks in rural areas would resemble the costs of FTTP drops – but providing only a fraction of the capacity in the process.

Aside from these two bands, there is nowhere else within the mid band spectrum that a wireless provider could amass enough spectrum. Sometime in the future, it may be possible to aggregate enough spectrum across multiple licensed bands to provide higher speeds approaching a Gigabit consistently, but the technology has not yet been deployed to do so and it is unclear when it will in fact become available. Furthermore, even if it were available, the distances over which a customer could be served would be limited by the shortest reach of all the aggregated frequencies.

Much attention has been giving to the recent CBRS and C-Band auctions with respect to rural broadband. We agree that these bands will be critical to providing improved broadband to rural customers that have been on the wrong side of the digital divide. However, our purpose here is to identify the mid band spectrum that can deliver RDOF Gigabit Services, which is significantly more challenging than a couple hundred megabits per second that might be achievable under certain conditions using the CBRS and C-Band. The total amount of spectrum available in the CBRS band, when including both the licensed and lightly licensed portions is only half of what would be needed to deliver RDOF Gigabit Services to a *single* customer. Furthermore, the maximum amount of spectrum that could be secured by any one bidder was only 40 MHz. Because of this, CBRS is not a realistic option for delivering RDOF Gigabit Services.

C-Band, on the other hand, may have enough spectrum to deliver RDOF Gigabit Services to a very small pocket of customers that are very close to the tower if a provider had access to the entire C-Band spectrum (280 MHz). However, it would be very unlikely that one of the RDOF winners could have secured enough of the 280 MHz in any given area. Furthermore, the RDOF areas are generally outside of the top 46 PEAs, so there is no requirement for this C-Band spectrum to be cleared until December 5, 2023. This would likely not be soon enough for the RDOF awardee to deploy a wireless network using C-Band spectrum in time to meet their first buildout requirement.

Likewise, the EBS band consists of only 116.5 MHz of spectrum if the bidder were able to secure all three of the EBS licenses. Not only is this not enough to deliver RDOF Gigabit Services, but the auction has not yet occurred. It would not be appropriate to award RDOF areas to a bidder that was counting on the possible success in a future FCC auction. It is important that any spectrum that a bidder is relying on to deliver any RDOF services be secured prior to the FCC awarding them the RDOF areas.

Some believe that additional mid band spectrum will be released by the FCC and eventually stem this inevitable capacity insufficiency. However, it is important to recall again that over 85% of the mid-band spectrum currently available, or even contemplated for use for fixed wireless broadband, is *shared-use.* Shared-use spectrum has been allocated by the FCC to two or more different purposes and fixed wireless uses are often the secondary user

[17] *Per* 47 CFR §15.407(a)(3), "fixed point-to-point U-NII devices operating in this band may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter conducted power. Fixed, point-to-point operations exclude the use of point-to-multipoint systems, omnidirectional applications, and multiple collocated transmitters transmitting the same information." There is good reason for this – allowing high power without these exclusions, even if automatically frequency coordinated, will raise the noise floor for everyone and will only lead to limiting of available channels for everyone and further overcrowding of the band.

and must protect the existing services of the incumbent. To do this, fixed wireless providers have modest permissible power limitations. To compound these mid band problems, nearly *two thirds* of the spectrum is governed by the U-NII[18] (generally, "Unlicensed" or "Part 15") service rules, and thus comes with *much* lower permissible power[19] and lower associated range.

There is also no guarantee that enough of this shared-use spectrum will *continue to* become available, especially in the exponentially increasing volumes necessary to support future demand demands. Despite the efforts of the FCC to free-up scarce mid-band spectrum such as in C-Band and 6 GHz, it is far-fetched to believe that unimpaired bands in a necessarily shared-use arrangement among primary and other secondary users in such coveted spectrum can be found and freed-up *indefinitely*, and in the *exponentially* increasing volumes necessary within the narrow and *finite* mid-band range, to match exponentially increasing fixed demand volumes – and that is even if one accepts that the coverage range limitations of mid-band spectrum could suffice for non-town, rural fixed applications.

In short, for Gigabit level service to become viable as a widespread commercial broadband solution in rural areas over fixed wireless technologies, there are at least four important technical barriers that must be addressed first: (1) more mid band spectrum would be needed (even beyond that identified as being in the pipeline now); (2) more contiguous channels of capacity would be needed for individual providers within those bands; (3) new equipment would need to be developed to aggregate spectrum within or across those bands; and (4) power and range limitations arising out of shared uses of such unlicensed spectrum.

RDOF Gigabit-Level Services Using mmW Bands

If such technical challenges persist in the offering of Gigabit services in rural areas leveraging mid band spectrum, it is logical to ask whether mmW spectrum, which is already being used to achieve higher speeds in densely populated, more urban environments, might be extended to offer Gigabit speeds in rural areas instead? While vendor claims and product specifications in the lead-up to the RDOF auction sought to justify promises of capability to deliver Gigabit speeds in rural markets based upon limited deployments in urban areas, careful engineering analysis against objective technical standards shows where these claims fail.

We showed previously that a few hundred MHz would be required to support just a handful of customers receiving RDOF Gigabit-Level Services. While, as discussed above, there is no such capacity readily available and acceptable for use within mid band spectrum, there would appear in theory to be enough spectrum available to do RDOF Gigabit-Level Services in the mmW band. More specifically, the bands that could be used include:

- Upper Microwave Fixed Use Service (UMFUS)
    - "24 GHz band" – 24.25-24.45 GHz and 24.75-25.25 GHz (Auction 102)
    - "28 GHz band" – 27.5-28.35 GHz
    - "37 GHz band" – 37-38.6 GHz
    - "39 GHz band" – 38.6-40 GHz
    - "48 GHz band" – 47.2-48.2 GHz band (Auction 103)

[18] *See* 47 CFR §15

[19] Compared to up to a few thousand Watts (depending upon sector arc) that is permissible for 2.5 GHz EBS/BRS – which represents only 13.4% of mid-band spectrum potentially available to independent operators, and of which the large majority of current licenses are controlled by T-Mobile, only up to 50 Watts per channel is permissible for "lightly licensed" 3.5 GHz CBRS, and only up to 4 Watts is permissible for Unlicensed.

- V-Band
  - “60 GHz band” – 57-71 GHz (Unlicensed)

These mmW bands have channel widths ranging from several hundred MHz of spectrum to a few GHz of spectrum, which is in theory more than enough needed to provide RDOF Gigabit-Level Services.

But a rigorous and disciplined technical analysis cannot and must not stop there. An essential and immutable characteristic of spectrum is that the higher it is in frequency, the less propagation and penetration power it will have. Frequencies in the mmW band can only propagate to very short distances before decaying to unusable levels when used in wireless networks. In addition, these frequencies are highly susceptible to fading due to diffraction by rain and moisture, and even to absorption by oxygen molecules. The result is that their usable reliable range – even on a clear day – is measured in the hundreds of feet, not in miles. This, along with the fact that they do not penetrate buildings or other obstacles such as foliage and must have an unobstructed Line-of-Sight (LOS) path makes high frequencies very undesirable for serving rural customers. Because mmW cannot penetrate walls, it is necessary that the customer install an antenna on their house or a nearby structure (such as a pole) that has clear LOS to the provider’s transmitting antenna. Using indoor customer equipment similar to what can be used at low and mid band frequencies is not possible when using mmW bands. Because of this, customer installs are typically more challenging and often require a professional installation. They can also become unreliable or stop working altogether if the LOS is partially or fully lost due to an obstruction such as new building or tree growth.

Applying such considerations to the areas auctioned off in the RDOF highlights the technical impediments to any proposals or vendor claims of capability based upon use of mmW bands. The areas to be served through the RDOF awards are some of the most rural areas in the country. Many of these census blocks are a few miles across and were auctioned off as part of larger census block groups, which could have been 10 miles across or more. Some of these census blocks or census block groups have smaller clusters of homes within them, but most of the census block groups have multiple census blocks that contain sparsely populated customer locations. Because of this, it is likely that the wireless equipment will need to provide broadband service several miles from central tower sites; otherwise nearly every customer would require his or her own tower given propagation limitations.

Realities on the ground in rural America only compound the challenges of using mmW spectrum to deliver high speed broadband and confound the claims of vendors based upon laboratory or limited urban conditions. To make it more difficult to deploy mmW wireless systems in rural areas, it is also common for homes to be behind a “shelterbelt.” Shelterbelts are lines of tall trees planted around one’s property to block prevailing winds from wreaking havoc on one’s home, and in colder climates, to prevent drifting snow on the downwind side. Customers living in rural areas must intentionally plant shelterbelts to protect their homes, especially necessary during the colder months. Consequently, where there is not already dense tree and foliage growth we often find shelterbelts. In either case, there is a strong possibility that trees will obstruct the radio path – which is especially devastating for higher frequency bands like mmW. This is a realistic example of the less than perfect conditions that will be encountered by many RDOF awardees which will further reduce the distance at which a single user may expect wireless broadband service.

In its RDOF auction comments arguing for the ability for fixed wireless providers to submit gigabit-level bids, WISPA identified equipment from four vendors that claimed to be “producing and distributing inexpensive equipment that can enable Gigabit service."[20] Yet, the very vendor data sheets included with the comments in fact highlight some of these challenges that companies will face when used to serve customers in rural markets. As described previously, the equipment would need to support a minimum of 1.5 Gbps (to account for both the downstream and upstream to provide RDOF Gigabit-Level Services) for a *single* user, which some of the equipment is unable to provide. In addition, the short distances over which the materials indicated that the equipment *can* provide broadband reveals the challenges these vendors will have providing services in the kinds of rural areas presented in the RDOF auction.[21] More specifically:

- Siklu Multihaul – Operates in the 60 GHz band. The base station has an aggregate throughput of 1.8 Gbps and end user terminals have an aggregate throughput of 1.0 Gbps. Not only is that not enough total capacity available to provide the needed 1.5 Gbps to meet the RDOF Gigabit-Level Service requirement but the equipment has a typical reach of only 900-1,300 feet (approximately a quarter of a mile), which even putting aside LOS concerns, hardly squares with densities in many rural markets.
- Adtran Metnet – Operates in the 60 GHz band and others. Has a range of 1,640 feet (approximately a quarter of a mile) at a capacity of 1 Gbps at the end user in a mesh configuration.
- IgniteNet MetroLinq – Operates in 60 GHz band and others and claims to enable an Over the Air (OTA) rate of 4 Gbps per sector. However, as one of the most prominent wireless Internet service providers itself has noted, it is not uncommon for the actual equipment data capacity to be one third to a half of the OTA line rate.[22] In addition, even with its highest gain and largest CPE antenna available (35 cm) the range is limited to only 2,270 feet (0.43 miles).
- RADWIN TerraWin – Operates in the 60 GHz band. Operates in a mesh network configuration and claims to have up to 3.6 Gbps throughput per user. No distances are given but does not claim to be a solution for rural areas.

This kind of equipment is often used for 5G small cell wireless backhaul or connectivity in densely populated areas where a single base station can reach several customers within a short distance (typically around 1,000 feet). In addition, as noted previously, there must be clear line of sight between the tower and each customer, which is often difficult, if not impossible, in rural areas due to the terrain, trees, and shelterbelts. Even though the vendors above quote longer distances, they are not able to RDOF Gigabit Service on a PtMP basis to even a small number of customers at these distances. When using mmW PtMP systems, the distance the customer could be from the provider antenna would be limited to only be a few hundred feet – likely around 500 feet if they are to ensure reasonable reliability.

These are not theoretical difficulties; practical experience in deploying mmW networks illustrates these challenges: Scott Mair, President of AT&T Operations, referred to AT&T's experience with its mmW deployment at a recent conference[23] by saying, ". . . millimeter wave provides unique characteristics in terms of bandwidth and speed. And that is going to play a part. But the millimeter wave and the propagation properties of that, take

[20] WISPA "Comments of the Wireless Internet Service Providers Association", AU Docket No 20-34, WC Docket No. 19-126, WC Docket No. 10-90, March 27, 2020.
[21] Ibid, Appendix A.
[22] Geolinks Ex Parte, "Competitive Bidding Procedures and certain Program Requirements for the Rural Digital Opportunity Fund, AU Docket No.20-34, May 29, 2020, page 2.
[23] AT&T Inc at Barclays Global Technology, Media and Telecommunications Conference, December 9, 3030.

your pick anywhere, 200, 300, 350 yards, is really not going to fulfill a coverage layer need for 5G."[24] Even after deploying in 36 cities, Mair went on to say, "And for the most part, it's enterprise use cases and maybe what I would call venue-specific use cases that we're using it for at this point."[25] These venue-specific places were not rural areas, but Mair said they were "Entertainment districts and stadiums, health care and manufacturing plants are kind of the business side, if you will, the enterprise side, with a lot of promise. And in those areas, I mean, the economics work really well, dense traffic specific use cases."[26] In short, AT&T has found that mmW-based services work well in dense traffic areas, but not in the kinds of rural areas at issue in RDOF. Neville Ray, President of Technology at T-Mobile has said regarding the mmW deployments currently underway for 5G, "Verizon's mmWave-only 5G plan is only for the few. And it will never reach rural America" he added, "Some of this is physics – millimeter wave (mmWave) spectrum has great potential in terms of speed and capacity, but it doesn't travel far from the cell site and doesn't penetrate materials at all. It will never materially scale beyond small pockets of 5G hotspots in dense urban environments."[27] Qualcomm, which makes many of the underlying hardware used for 5G and mmW equipment has similarly indicated, "mmWave best accommodates dense urban areas and crowded indoor environments. . . "[28] Hans Vestberg, Verizon Communications Chairman and CEO, has likewise said of mmW, "We all need to remind ourselves this is not a coverage spectrum because we will do it as far as the economic is sustainable, of course."[29]

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[24] Ibid, page 6.
[25] Ibid, page 6.
[26] Ibid, page 7.
[27] Neville Ray blog post, April 22, 2019, https://www.t-mobile.com/news/network/the-5g-status-quo-is-clearly-not-good-enough
[28] Understanding mmWave: Faster connectivity highways for 5G, The OnQ Team, November 28, 2018, https://www.qualcomm.com/news/onq/2018/11/28/understanding-mmwave-faster-connectivity-highways-5g
[29] Q1 2019 Verizon Communications, Inc. Earnings Call, April 23, 2019.

Summary/Conclusions

Wireless networks play an important role in connecting customers – but when it comes to assessing the justification for expending public or private funds for broadband deployment, it is equally important to take a realistic picture of the capabilities and limitations of such networks. The broadband speeds promised by future wireless technologies may sound promising, but marketing claims and tests under ideal conditions are no substitute for a rigorous and disciplined technical analysis of what such networks can and cannot deliver.

The promise of wireless solutions deliver RDOF Gigabit-Level Service appears difficult to justify in most rural applications. Apart from some very limited circumstances presenting ideal conditions as summarized herein, the technical and related economic hurdles will be substantial, if not insurmountable.

Mid band spectrum may have adequate reach to provide service to customers in rural areas, but there are significant challenges with current technologies and spectrum to provide even 100 Mbps service to sparsely populated areas, much less the Gigabit services promised in the RDOF auction. The spectrum is very desirable for wireless broadband services but there simply is not enough of it available to accommodate most RDOF winners. Use of the crowded unlicensed bands, such as 5.8 GHz, should be rejected due to reliability issues associated with unlicensed frequencies, especially when considering the RDOF voice requirements that must provide reliable access to emergency services such as 911. In short, considering objective engineering criteria, there is no viable path currently available to offer reliable RDOF-Level Gigabit Services in rural America leveraging mid band spectrum.

Providing RDOF Gigabit services in the mmW band presents different challenges – but challenges nonetheless. The mmW band has adequate spectrum to deliver RDOF Gigabit-Level Services, but the spectral characteristics are not well suited to provide rural broadband as was the subject of the RDOF auction. In most areas, using mmW would require each rural resident to have his or her own wireless tower. Most of these towers would be required to have fiber connections to deliver the needed broadband capacity to the network connection point.

When considering any proposed wireless network designs based on mmW technologies for any RDOF bidder to satisfy its Gigabit service commitment, the FCC should verify the following:

1. All customers must be within about 500 feet of their specific serving tower/antenna.
2. All customers must have clear line-of-sight to that serving tower/antenna.
3. The capacity of the serving tower/antenna or sector must be adequate to accommodate the downstream and upstream capacities of all users served by that antenna or tower.
    a. The RDOF 70% subscription requirement must be considered in analyzing the capacity of the service tower/antenna or sector.
    b. A reasonable oversubscription ratio on the order of 4:1 or less should be applied.
4. Each antenna and/or sector must also have adequate backhaul capacity to accommodate the number of RDOF customers anticipated with a reasonable oversubscription ratio such as 4:1. In most instances this will require the towers/antennas to be served with a fiber network.
5. When considering mmW mesh networks, in addition to the preceding factors, the FCC should also evaluate the congestion that would occur between the nodes of the mesh network as well as the potential radio frequency congestion and the backhaul congestion.

Author Biography

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Larry Thompson is a licensed professional engineer and has been designing satellite, wireless, and broadband wireline networks for more than 30 years. Larry received his bachelor's degree in physics from William Jewell College and his bachelor's and master's degrees in Electrical Engineering from the University of Kansas. Prior to founding Vantage Point Solutions in 2002, Larry held several engineering and management positions with TRW's Space and Defense sector, CyberLink Corporation, and Martin Group. Larry is currently the CEO of Vantage Point Solutions, which has over 400 employees and is a national provider of engineering and consulting services. Over the years, he has assisted many wireless and wireline companies successfully manage their technical, regulatory, and financial challenges.

Larry serves on the FCC's Broadband Deployment Advisory Committee (BDAC), he is a frequent speaker at state and national conferences and a frequent expert witness at utility commission and legal proceedings relating to telecommunication technology and regulatory matters.

About Vantage Point Solutions

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