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Evaluating 5G Wireless Technology as a Complement or Substitute for Wireline Broadband

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Executive Summary

The Internet has had profound impacts on nearly every area of our lives, including education, retail, healthcare, public safety, and entertainment. The Internet has transformed 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. 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 TV (UHDTV) becomes commonplace, and with the dramatic growth of connected devices of all kinds needing Internet access.

When considering the most effective and efficient use of public and/or private resources to invest in networks, it is necessary to understand these current and future user demands to determine the type networks needed to meet these increasing demands over the life of the network assets. As providers of all kind compete for consumers, not all broadband technologies are created equal. Some broadband access technologies offer the promise of mobility – an important factor for many consumers. Others can be installed quickly and at somewhat lesser cost upfront, but their ongoing costs may be high – and the need may soon arise to reinvest in the network if demand is expected to increase, limiting or eviscerating any upfront cost savings. Still others are better suited to meet consumer and business broadband demands of the future.

Satellite broadband, for example, will continue to suffer from limitations that are difficult or impossible to overcome if one is attempting to keep pace with the many applications that drive consumer demand.[1] Meanwhile, terrestrial wireless carriers have pinned much of their hopes on new, emerging standards often referred to as 5th Generation or "5G" wireless technology. In fact, large wireless companies are already hyping so-called "5G" deployments, despite the fact that we are years away from even just a 5G standard, let alone deployment. Today, 5G is primarily a marketing term, and often a misleading one. When the average consumer hears about a "5G" deployment, the consumer may assume it means that gigabit cell phones are around the corner. But this is not the case. Companies are misusing "5G" today to describe small cell 4G technology being used to fill gaps or relieve congestion, or for technology to provide faster indoor-only wireless connections using millimeter wave spectrum for or in competition with Wi-Fi.

An engineering analysis indicates that true 5G wireless technologies will, like their predecessor technologies, be an important and very useful complement to wireline networks; certainly in the mobile context, it is reasonable to expect significant consumer demand for services that offer the promise of higher speeds and greater reliability. And, to be clear, there will be discrete situations in which the use of 5G in connection with fixed wireless offerings will be useful and necessary to extend service initially or perhaps to enable service to certain locations that are so remote that they are unlikely to ever receive wireline service in the near future.

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[1] Analysis of Satellite-Based Telecommunications and Broadband Services, Vantage Point Solutions, November 2013. (https://ecfsapi.fcc.gov/file/7520956713.pdf)

But from a technical perspective, even in a fixed context, wireless technologies should be viewed as a complement – a tool in a toolkit – rather than a viable widespread substitute for wireline broadband networks. In fact, newer wireless technologies will rely more heavily than any predecessor wireless technology upon far deeper penetration of wireline facilities. Undoubtedly, 5G wireless technologies will result in better broadband performance than 4G wireless technologies and will offer much promise as a mobile complement to fixed services, but they still will not be the right choice for delivering the rapidly increasing broadband demanded by thousands or millions of households and businesses across America.

Previous analysis of 4th generation (4G) wireless networks[2] clearly demonstrated how these networks, even with generous capacity assumptions for the future, will have limited broadband capabilities, and inevitably will fail to carry the fixed broadband experience that has been and will be demanded by subscribers accustomed to their wireline counterparts. Although there is understandably much anticipation today about phenomenal possible speeds for 5G wireless networks tomorrow, they will continue to have technical shortcomings that will, like their predecessor wireless networks, render them very useful complements but poor substitutes for wireline broadband. These technical challenges include:

- Spectral limitations: 5G networks will require massive amounts of spectrum to accomplish their target speeds. At the lower frequencies traditionally used for wide area coverage, there is not enough spectrum. At the very high frequencies proposed for 5G where there may be enough spectrum, the RF signal does not propagate far enough to be practical for any wide area coverage. This is particularly important in rural areas where customer concentration is far, far less than what can be expected in densely populated urban areas where 5G may offer greater promise.
- Access Network Sharing: This is not a good solution for continuous-bit-rate traffic such as video, which will make up 82% of Internet traffic by 2020.
- Economics: When compared to a 5G network that can deliver significant bandwidth using very high, very short-haul frequencies, FTTP is often less expensive and will have lower operational costs. This is particularly true when one consider how much fiber deployment will be needed very close to each user even just to enable 5G.
- Reliability: Wireless inherently is less reliable than wireline, with significantly increased potential for impairments with the very high frequencies required by 5G.

All broadband providers today – wired and wireless alike – realize that the way to increase broadband capability is to increase the amount of fiber in their network. Landline providers are replacing their copper cable with fiber, cable operators are replacing their coax cable with fiber, and even wireless providers are actually replacing their wireless networks with fiber by placing their towers (or small cells) closer to the customer.

[2] Wireless Broadband is Not a Viable Substitute for Wireline Broadband, Vantage Point Solutions, March 2015 (http://www.ntca.org/images/stories/Documents/fixedwirelesswhitepaper.pdf).

Today, wireless networks rely heavily on the wireline network, and this reliance will only increase with 5G since only a small portion of the last-mile customer connection (i.e., the "local loop") will use wireless technologies. 5G networks are predominantly wireline deep fiber networks,[3] with only a very small portion of their network using a wireless technology. This small wireless portion of the network determines the ultimate broadband capacity of the network, since it is the network bottleneck. As an analogy, we all have been on a multilane highway when road construction or an accident required traffic to be funneled into a single lane. This is similar to what happens when the broadband capacity of a fiber is constricted by a 5G wireless network when serving a customer.

In an attempt to address such challenges, there are three basic ways broadband capacity can be increased in wireless networks from a technical perspective. These are:

1. Increase transmit power (or reduce noise) to permit better modulation techniques
2. More spectrum – or more re-use of the same spectrum in the same cell
3. Fewer users per cell

The transmit power allowed is controlled by federal regulation. Noise will not improve, and in fact will only worsen as more and more transmitters are added in the closely spaced adjacent cells. Without improvement of the former over the latter, higher efficiency modulation techniques would only be usable by a very few cell users, providing little improvement in overall capacity. Because of this, 5G wireless increases the broadband capabilities through the use of more spectrum and fewer users per cell. Unfortunately, the only spectrum available for use by 5G is so high in frequency that the propagation loss and environmental impacts are extremely significant. These high frequencies also have poor penetration capabilities.

To overcome these shortcomings, the 5G wireless cells must be placed very close to the customer (often within 300 to 500 feet), which makes 5G particularly impractical for most rural applications. In the following pages, we explore how one can assess and validate the capabilities of proposed 5G wireless network deployments in real world environments and determine where they may or may not be practical or economical to deploy, as well as whether they will indeed fulfill the consumer demand they purport to achieve. But first, we begin by determining what broadband speed and capacity a broadband network needs to deliver to meet customer needs and be competitive in the future.

[3] A "deep fiber network" is a network where the network serving the customer is predominantly fiber and the fiber from the central office either terminates at the customer premise or terminates close to the customer premises.

Broadband Today and Tomorrow

In a previous whitepaper, Vantage Point Solutions described the specific technical metrics that defined high quality broadband, which are:[4]

- High Speed
- Low Latency
- High Capacity
- High Reliability
- Economical and Scalable

Although all five metrics are important for broadband networks of the future, we will focus primarily on the speed and capacity requirements in this section. This will help us better understand what will be required from a 5G network to meet the broadband needs of a single customer – and many customers over wide service areas.

User Demands

The Internet connects people and machines throughout the world and has changed the way we communicate, educate, provide healthcare, and buy and sell goods. In recent years, we have seen the launch and rampant growth of e-commerce sites like Amazon, sites that are used for both news and social purposes like Facebook and Twitter, video communications services like Skype, and video streaming services such as Netflix and YouTube, as well as Instagram, Snapchat, and hundreds of other sites and applications we take for granted today. The Internet of Things (IoT), smart grid and smart city applications, and distance learning and telemedicine functions are also only in nascent stages of anticipated exponential growth. Cisco believes that Internet traffic will continue to grow by 22% annually through the year 2020.[5] In 3 short years, it is estimated that there will be 26.3B devices connected to the Internet[6] and the average US household will have 12.18 devices.[7]

Understanding traffic patterns and demands on the Internet will help us better understand what type of network is best suited to deliver the traffic. Applications that have become a part of our everyday lives and require quality broadband connections include:

- Distance Learning - There are hundreds of online options available for primary, secondary, and postsecondary schools. These opportunities expand the reach of the teacher and

[4] Wireless Broadband is Not a Viable Substitute for Wireline Broadband, Vantage Point Solutions, March 2015, pg. 7-10 (http://www.ntca.org/images/stories/Documents/fixedwirelesswhitepaper.pdf).
[5] The Zettabyte Era: Trends and Analysis, June 2016, Cisco, pg. 3. (http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/vni-hyperconnectivity-wp.html)
[6] The Zettabyte Era: Trends and Analysis, June 2016, Cisco, pg. 2
[7] The Zettabyte Era: Trends and Analysis, June 2016, Cisco, pg. 6.

provide educational options for the student that were not previously available. Some colleges, such as the University of Phoenix and Liberty University have many more online students than on their campus. Distance learning is becoming increasingly important, especially in rural areas where access to quality schools and teachers locally, especially in diverse or technical disciplines, is not always possible.

- Healthcare - Remote telemedicine[8] has the promise of dramatically improving the quality of healthcare especially for those in rural areas that do not have easy access to doctors or hospitals. Telemedicine can not only provide patient monitoring, but can shave hours off the critical time between a medical emergency and the patient's treatment.
- Video Chat and Video Conferencing - Person-to-person and business-to-business communication is moving from voice to rich multimedia content. Online video tools such as Skype, FaceTime, and Google Hangouts allow people and employees to meet without being physically present.[9]
- Entertainment - Netflix accounts for more than one-third of all Internet traffic in North America.[10] Additionally, other streaming video providers such as Amazon Video, Hulu, YouTube, and traditional broadcasters have large shares of the Internet traffic. The broadband speed requirements for the on demand streams are increasing as video resolutions increase from high-definition to ultra-high-definition (UHD).[11] According to Netflix, UHD streams require 25 Mbps per stream.[12] Therefore, if different members of a household were watching UHD on two different devices, 50 Mbps would be required just for these two streams.
- Cloud Computing - Microsoft cloud products are predicted to be 30% of their revenue by 2018 and other platforms such as Amazon Web Services (AWS) are experiencing large revenue growth.[13]

Many of the broadband drivers including distance learning, remote telemedicine, video conferencing and entertainment involve the delivery of video over the Internet. Cisco believes that IP video traffic will account for 82 percent of the Internet traffic by 2020.[14] This is significant, since some network technologies are better suited than others for delivering continuous bit rate

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[8] According to the American Telemedicine Association, telemedicine and telehealth can involve "Videoconferencing, transmission of still images, e-health including patient portals, remote monitoring of vital signs, continuing medical education and nursing call centers are all considered part of telemedicine and telehealth." (http://thesource.americantelemed.org/resources/telemedicine-glossary)

[9] 15 Trends Every Business Leader Should Watch in 2017, Fortune, Chirag Kulkarni, January 3, 2017, (http://fortune.com/2017/01/03/2017-tech-trends/)

[10] More than a Third of North American Internet Traffic is on Netflix, Speed Matters, June 27, 2016 (http://www.speedmatters.org/news/more-third-of-north-american-internet-traffic-on-netflix)

[11] 1080p high definition video has a resolution of 1,920 by 1,080. Ultra-high-definition video has a resolution of 3,840 by 2,160.

[12] Internet Connection Speed Recommendations, Netflix website, (https://help.netflix.com/en/node/306?ui_action=kb-article-popular-categories)

[13] Roundup of Cloud Computing Forecasts and Market Estimates 2016, Forbes, Louis Columbus, March 13, 2016 (http://www.forbes.com/sites/louiscolumbus/2016/03/13/roundup-of-cloud-computing-forecasts-and-market-estimates-2016/#4472fbb074b0)

[14] The Zettabyte Era: Trends and Analysis, June 2016, Cisco, pg. 15

(CBR) applications such as video. Networks that dedicate capacity to each customer, as is the case with most landline technologies, are better suited to deliver this type of traffic than networks that share capacity among many users. CBR traffic such as video will increasingly dominate the Internet. Wireless networks share capacity among many users. Delivering video to a customer continuously for a two hour movie means that capacity is not available during this time for another user. This limitation is discussed later in more detail.

The Future of Broadband

Broadband providers of all kinds continue to invest heavily in their networks to help ensure they are prepared to meet the customer demands of the future. Charter Communications Chairman and CEO Tom Rutledge has said that the cable operator is “moving toward a future where broadband speeds of up to 10 Gigabits per second are possible.”[15] Verizon soon will be offering a 750 Mbps tier in their FIOS markets in NYC, New Jersey, Philadelphia, and Boston.[16] AT&T currently is offering gigabit services in many of their markets and has it planned for many more,[17] while Comcast is offering a 2 Gbps service in many of their markets.[18] Google Fiber offers 1 Gbps in several cities today.[19]

Nielsen’s law, theorized by Jakob Nielsen, PhD[20] in 1998, states that broadband bandwidth demand grows at a rate of 50% a year for high-end users.[21] The broadband connection experience over the years and its reasonable projection shown in Figure 1 supports his theory that broadband speeds can be expected to continue to rise at similar rates.[22]

Although some would argue that 1 Gbps already is common today in larger cities, Figure 1 projects it to be commonly available before 2020.

[15] Charter Eyes 10Gbps Broadband, Multichannel News, December 6, 2016 (http://www.multichannel.com/news/cable-operators/charter-eyes-10gbps-broadband/409489)

[16] Verizon Goes on the Offensive with Cable, Launches 750 Mbps Symmetrical Service, Telecompetitor, January 12, 2017 (http://www.telecompetitor.com/verizon-goes-on-the-offensive-with-cable-launches-750-mbps-symmetrical-service)

[17] AT&T names 11 new metro areas for gigabit fiber Internet, ARS Technica, October 5, 2016 (https://arstechnica.com/information-technology/2016/10/att-names-11-new-metro-areas-for-gigabit-fiber-internet/)

[18] Comcast’s 2Gbps Internet costs $300 a month with $1,000 startup fees, ARS Technica, July 13, 2015 (https://arstechnica.com/business/2015/07/comcasts-2gbps-internet-costs-300-a-month-with-1000-startup-fees/)

[19] Google Fiber Website, (https://fiber.google.com/about/)

[20] Nielsen Norman Group website (https://www.nngroup.com/people/jakob-nielsen/)

[21] Nielsen’s Law of Internet Bandwidth, Jakob Nielsen, Updated 2016, (https://www.nngroup.com/articles/law-of-bandwidth)

[22] Nielsen Norman Group website (https://www.nngroup.com/people/jakob-nielsen/)

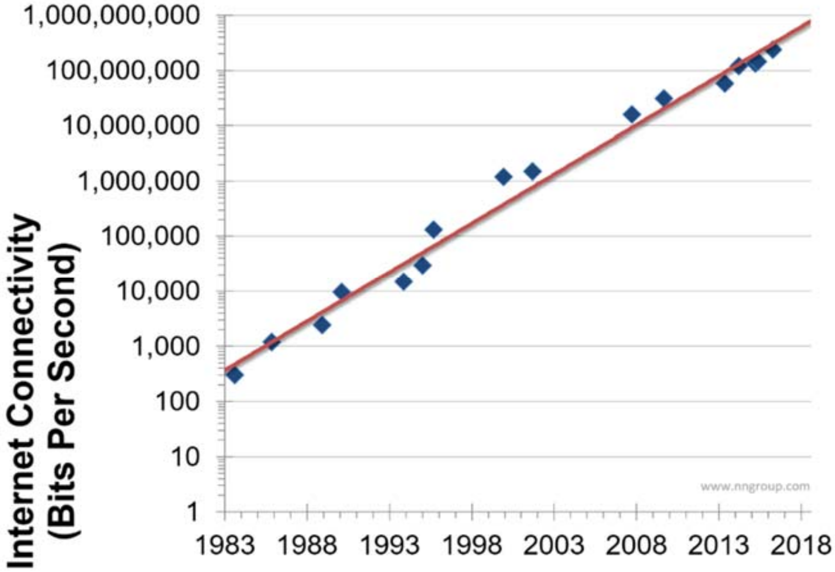

Figure* 1 – *Jakob Nielsen - Predicted Broadband Demands

What is commonly available, as shown in Figure 1, is greater than the median broadband speed across all consumers. The FCC reported[23] that the median speed in September 2015 was 41 Mbps, which represented an increase of 28% increase over the previous year's median speed of 32 Mbps. This is consistent with other measurements published by the FCC.[24] If we were to assume that the growth rate will continue at a rate of 28% annually, 100-150 Mbps will be the median average speed when 5G networks become available. If we assume that the equipment life expectancy will be 8 years, the median broadband speed would be 1 Gbps at the equipment end of life if it were installed in 2020.

With this as a backdrop, we will analyze the broadband capabilities of 5G networks that are needed to satisfy this sort of demand for greater speeds and capacity.

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[23] 2016 Measuring Broadband America Fixed Broadband Report, Federal Communications Commission, pg. 15 (http://data.fcc.gov/download/measuring-broadband-america/2016/2016-Fixed-Measuring-Broadband-America-Report.pdf)

[24] The Broadband Availability Gap, OBI Technical Paper No. 1, pg. 42 assumed an average annual growth rate of 26%. (https://transition.fcc.gov/national-broadband-plan/broadband-availability-gap-paper.pdf)

Validating 5G Wireless Capabilities

Vantage Point's March 2015 paper on wireless technologies[25] clearly demonstrated how 4th generation wireless networks, even with generous capacity assumptions for the future, will have limited broadband capabilities, and inevitably will be unable to match the fixed broadband experience demanded by subscribers accustomed to their wireline counterparts. That paper also explained how, when viewed from the perspective of meeting current and anticipated demand growth over the life of the network assets, investment in wireline technologies typically represented a far better use of limited investment resources. Since that time, much has been promoted about phenomenal speeds to be supported by 5th Generation (5G) networks. We therefore shall take a closer look.

What Is 5G?

Revolutionary or Evolutionary?

As we shall see, 5G may represent substantial progress, but it is still more evolutionary than revolutionary. While promising for consumers to be sure, particularly in the mobile service context as compared to 4G services, 5G is the result of wireless technologies simply being driven by classic limits of physics to evolve naturally from the previous generations, in order to meet the rapidly growing mobile bandwidth demand. It is targeted primarily at and most effective in densely populated areas, and at very low-demand, very occasional-use sensors and actuators that will amass with the forthcoming "Internet of Things" (IoT). Our focus here is to explore 5G's possible viability for high-capacity broadband wireless substitution. For reasons we will discuss, 5G necessarily must evolve into very densely deployed "small cells." It thus is highly unlikely to replace 4G for coverage "out of town," and it thus will not be a solution for the "digital divide" affecting those areas.

Understanding and Unpacking the Hype

5G has been touted to provide speeds 100 times faster than 4th generation wireless, as high as 10 Gbps, with latency approaching that of fiber (sub-10 ms). These speeds indeed sound fantastic! But this assumes unrealistic conditions and overlooks the critical fact that the capacity must be shared among multiple users. As we will show, it is essential to look beyond the understandable hype and understand in the context of each proposed deployment what 5G and other wireless technologies really can – and cannot – achieve. Again, wireless technologies can play an important, and even essential, role in helping to fulfill broadband objectives, especially in a complementary context for mobility purposes. But it is necessary to take objective stock of what wireless can and cannot do on a widespread basis, especially in rural areas and in the context of using certain kinds of applications.

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[25] Wireless Broadband is Not a Viable Substitute for Wireline Broadband, Vantage Point Solutions, March 2015 (http://www.ntca.org/images/stories/Documents/fixedwirelesswhitepaper.pdf).

Practical Throughput

Wireless vendors often promote their products by listing the fastest data connection rates possible. However, these are theoretical rates that would be possible only in a lab environment, and only for a single user who is located very close to the access point and able to utilize every single one of the best-case, unimpaired radio channel resources. This is completely unrealistic for real world dimensioning for capacity, and overstates an access point's practical capacity by 500% or more. This is because an access point cannot deliver peak speeds across its entire coverage area or "cell." Radio channel quality, and *ergo* its spectral efficiency[26] and data rate ability, deteriorate rapidly with distance, falling to half or less of peak at only 25% of the distance to the cell edge,[27] as depicted in Figure 2. This represents roughly only 6% of the cell's coverage area.

To determine a cell's overall *practical* capacity for broadband, and thus to help evaluate the real capability of any potential or proposed network deployment leveraging wireless technology, one must consider the *average* of the experience possible among *all* users near and far.[28] This is often only 15-25% of the theoretical peak for a single user. When overheads[29] are considered, the useable capacity will typically be less than 75% of this value. It therefore is not unusual for the actual capacity to be only roughly 15% (75% of 15%-25%) of its peak capacity – that which is usually "hyped," to assess the practical, sharable, usable throughput of a cell.

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[26] Spectral efficiency is a measure of how efficiently a wireless technology uses its allocated spectrum, much like a farmer might measure productivity in bushels per acre. It is expressed in bits per second (bps) carried, per Hertz (Hz, or cycles per second) of spectrum available to the radio channel (i.e., bps/Hz). For instance, a 10 MHz-wide radio channel carrying 10 Mbps of broadband traffic is performing with a spectral efficiency of 1 bps/Hz. Peak spectral efficiency and *ergo* broadband speeds are available very close to the access point, where the radio signal is very high compared to the surrounding interference and noise, enough for the receiver to be able to decode all of the subtle changes in the complex modulations of the radio signal that make the highest speeds possible. However this Signal to (Interference + Noise) Ratio or "SINR," and hence spectral efficiency, roll off as signal strength decays with distance. Worse, it does not roll off linearly with distance.

[27] A simplified expression of LTE standards body 3GPP's definition of the cell edge is the point at which a user's best available throughput is 5% of the total cell throughput. A practical definition would be the point along a radial from the access point at which the signal to noise ratio has decayed to a value insufficient to support useful decoding of the lowest order of modulation supported by the technology, (can be expected to occur at a BER of around 0.1), even utilizing the highest available amount of Forward Error Correction (FEC).

[28] The sum of all data rates experienced by all users compared to the amount of spectrum available to the cell, then, is the cell's *average* or "cell spectral efficiency." For an example, while the peak spectral efficiency for a cell utilizing 4G LTE technology in the latest generally deployed 4x4 MIMO configuration is 16.3 bps/Hz, its *average* or cell spectral efficiency is only 2.67 bps/Hz. On a 10 MHz-wide downlink channel, this results in a total practical cell data connection rate capacity - to be shared among all users, of only 26.7 Mbps, not 163 Mbps. After overheads [29], while peak throughputs occasionally experienced by a single user could be much higher, the practical usable cell throughput - to be shared among all users near and far, by which to dimension the cell for capacity, falls to 19 Mbps – again, not 163 Mbps.

[29] TCP/IP and Forward Error Correction (FEC) overheads

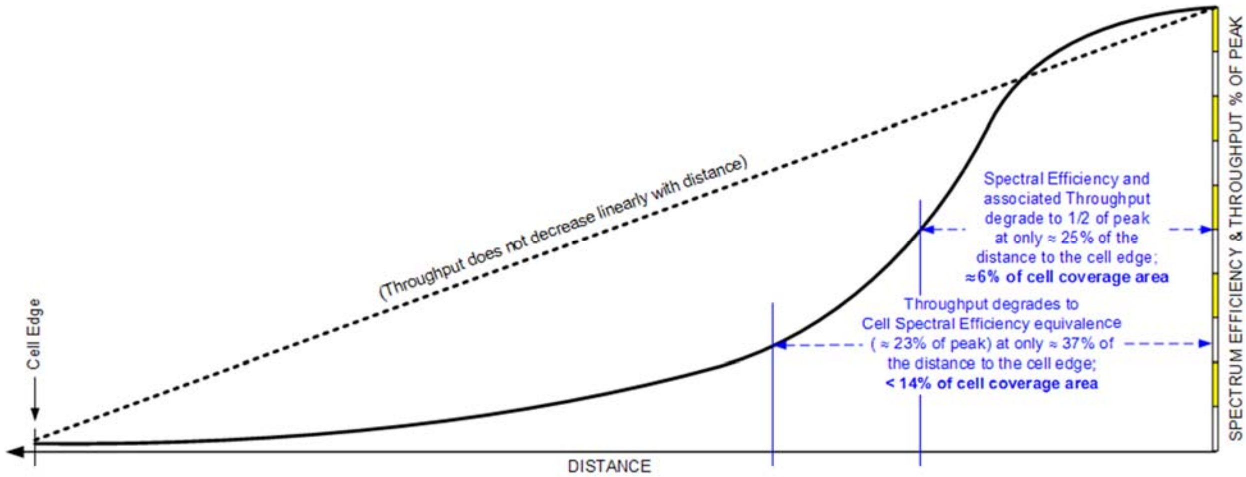

Figure 2 – Typical LTE Throughput vs. Distance

Three Ways to Get More Broadband With Wireless

Physics limit any wireless technology's evolution to provide more broadband to three methods. As mentioned previously, these are:

1. Increase transmit power (or reduce noise)
2. More spectrum
3. Fewer users per cell

We will address each of them and assess how 5G uses these three methods to provide more bandwidth and some of the shortcomings that are introduced in the process.

Method 1: Increase Transmit Power (or Reduce Noise)

One way to increase the capacity of a radio channel or stream, is to increase signal level or reduce noise,[30] including interference, (together, improve the SINR[31]) in order to enable better modulation techniques. FCC rules do not permit Signal levels (transmitter powers) to increase, and Noise will only get worse with more and more transmitters, (*ergo*, SINRs will only deteriorate). Without

[30] The maximum capacity of a medium to reproduce information at its distant end was characterized in 1948 by mathematician Claude Shannon, in his landmark paper on information theory called *A Mathematical Theory of Communication.* Shannon's Law is still used today to define the theoretical broadband capacity limit for a single wireless channel stream. The equation is as follows:

$$C = B_{\omega} log_2 \left[1 + \frac{S}{N}\right]$$

…where *C* is channel *Capacity* in bits per second, B_w is the *Bandwidth* in Hertz, *S* is the *Signal* power, and *N* is the *Noise* power.

[31] Noise in Shannon's equation [30] includes all undesired signal, including the thermal noise floor occurring naturally in electronic components, as well as the interference created by other unwanted transmitters and re-radiators. Thus, the Signal/Noise ratio in the equation often is referred to as the Signal to (Interference + Noise) Ratio, or SINR.

SINR improvement, higher efficiency modulation techniques would only be usable by a very few cell users. Therefore, while enabling the vendor to boast of higher possible peak rates, in practice it only would provide limited improvement in the access point's overall *practical* capacity for broadband. Improving broadband performance must therefore be accomplished by either more spectrum or fewer users per cell.

Method 2: More Spectrum

There is not enough spectrum in the sub-6 GHz bands used by traditional 4G sites to facilitate larger channel Bandwidths. Although some spectrum is being added with the 600 MHz auction, it is only a tiny fraction of what is required to support the 100x improvement requirement for 5G. Spectrum quantity for *mobile* broadband indeed is slated to improve in the next few years, however. As a result of its "Spectrum Frontiers" vote on July 14, 2017, the FCC intends to release and re-purpose for mobile broadband 18 GHz of so-called Millimeter Wave (mmW) spectrum - very, very high frequencies whose wavelengths[32] are measured in millimeters rather than meters, hence its moniker. These frequencies are in the 6 GHz to 80 GHz range.

Millimeter Wave Shortcomings

Figure 3 shows the spectrum available for fixed broadband that has been added since March 2015.[33]

One might wonder why these new mmW bands do not appear to improve the volume of spectrum available for fixed broadband by any significant amount. This is because these bands *always* have been available for fixed broadband, albeit some of them (39 and 80 GHz) only for point-to-point.

A trait of spectrum is that the higher it is in frequency, the less propagation and penetration power it will have. Frequencies this high only can propagate to very short distances before decaying to unusable levels; plus they 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, has rendered them of little use for conventional "macro" cells. For all of these reasons, they have not been considered usable to date for fixed broadband.

[32] Wavelength is the distance between electromagnetic wavefronts as they propagate through space at the speed of light. As light propagates at 300 million meters per second, a frequency's wavelength can be found by dividing this by the radio frequency. For instance, the wavelength for a 60 GHz radio carrier (60 thousand million cycles per second) is 300 million meters divided by 60,000 million cycles per second, or 5 millimeters (0.005 meters). For comparison, a 600 MHz radio carrier, as is being auctioned for 4G mobility currently, has a wavelength of a half a meter (0.5 meters).
[33] Because of the natural relationship of channel bandwidths compared to band frequency, for practicality the radio spectrum traditionally is shown on a quasi-logarithmic scale. Therefore, the portions of bandwidth in the Millimeter Wave band, while much larger in Hz than for bands in lower frequencies, do not appear graphically as large as they would if displayed linearly.

Figure 3 – Portion of Radio Spectrum Available for Broadband Added or Pending Since 2015 (In Red)

As networks increasingly must be densified into smaller and smaller cells in order to increase capacity by other means, as will be discussed below, mmW spectrum will become of increasing use for these "small cells," when densified to the point of having similar, relatively tiny coverage radii. Even so, though, while this may be of great benefit to outdoor-to-outdoor or indoor-to-indoor mobility, if suitable at all for fixed broadband, it will be only in dense, urban environments. And even then, practically, it would only be to outdoor Customer Premises Equipment (CPE), not directly to equipment indoors.

Some of carriers are considering the use of unlicensed 60 GHz to provide a wireless Gigabit service (often based on IEEE 802.11ad "WiGig"). But it will be challenging for any provider utilizing this spectrum to overcome all of the above issues that are intrinsic to this spectrum, as well as those that attend any Part 15 "unlicensed" spectrum.[34]

[34] It is true that larger theoretical throughputs due to available channel bandwidths wider than those typically available with licensed spectra today, are theoretically available with "unlicensed" (FCC 47 CFR Part 15) access points, typically utilizing the 2.4 and 5 GHz bands. However, whether Wi-Fi or vendor-proprietary technology, access points utilizing these bands are severely and inevitably hampered in both of the other two "variables" needed for higher capacity, as discussed in Method 1 – higher Signal, and lower Noise. Besides being very low in power and resulting range, as controlled by the FCC, they are fraught with increasingly serious noise (interference) levels today, due to the crowded and growing non-exclusive use of the bands. Regardless of technologies, this increasingly and significantly limits their capacities and

Within its tiny range, mmW spectrum will have available channel widths on the order of ten times as wide as current traditional cellular frequencies - which alone could result in up to a 10x improvement in access point capacity. But the GSM Association touts 5G as having potentially a *100x* improvement over 4G, targeting as much as 10 Gbps peak! How can this be possible?

Re-use Spectrum in the Same Cell (MIMO); Diminishing Returns

Ways to re-use a frequency at the same place at the same time can give the appearance of more spectrum quantity (*i.e.,* more Bandwidth, for Method 2). In fact, this already is being done today with the use of Multiple Input, Multiple Output (MIMO) air interfaces. But they do come with diminishing returns.

MIMO can permit portions of a user's data to be divided into parallel streams between the access point and the user, which utilize the same frequency at the same time. "2x2" MIMO is commonplace today (two antennas each at the access point and the user equipment). This can permit *peak* throughput speeds to be nearly doubled, but *overall cell* spectral efficiency only increases by a factor of around 160%. So-called "4.5G" LTE-Advanced will permit up to 8x8 MIMO, with a nearly corresponding 4x increase in possible *peak* user throughput compared to 2x2. But in this case, with four times as many antennas, receivers and transmitters, the overall cell spectral efficiency compared to 2x2 is only barely doubled. 4x4 MIMO is just now being employed by the cellular carriers.

With 5G, advanced forms of MIMO called Multi-User MIMO will use massive numbers of antennas at a site, which can form multiple individual beams to separate users. This will permit using the same frequency at the same time to serve each of the multiple users with capacity approaching what an otherwise conventional site might support in total, and without the beams interfering with one another much. But again, the improvement in overall throughput only goes up by a small

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spectral efficiencies to small fractions of their peak theoretical rates. Providers using these unlicensed bands to offer fixed broadband service today already are struggling to support more than a few subscribers per access point, even with only today's fixed broadband demand. This will only worsen as Wi-Fi continues to be used even more and more ubiquitously for "last few feet" access by portable devices, and as "HetNets" emerge, as discussed in following paragraphs. With little or no additional sub-6 GHz unlicensed spectra becoming available, (*i.e.,* Method 2), and with only worsening SINR, attempts to increase capacity otherwise with higher modulation rates, (*i.e.,* via Method 1), will only shorten ranges still further. And, as will be discussed in Method 3, simply adding more of them won't help. The first "HetNets", do contemplate the use of unlicensed 5 GHz for LTE, but only when concatenated with and anchored by a companion, fully-licensed channel, such that the unlicensed spectrum will be used only for best-effort overflow – to the extent it may be available at any given moment. And in reality, these arrangements are only attempts to render a preliminary, 5G-like experience, until eventual, frequency-managed and standardized use of mmW for true 5G can be deployed. For all of these reasons then, sub-6 GHz unlicensed access points, even attempting to use "5G-like" techniques, regardless of whether standardized or proprietary, will struggle and likely fall farther behind in trying to meet tomorrow's fixed broadband demands in all but the most remote, sparsely used and short-haul applications. Further, the susceptibility of systems on any unlicensed spectrum to being seriously debilitated by competing systems, which can appear close by without warning and without FCC recourse – whether sub-6 GHz or 60 GHz – render them risky choices by themselves for delivery of any 5G-like fixed broadband.

fraction of the increase in the number of antennas, and it requires much higher complexity and expense for both the access point and the user equipment.

Channel Concatenation, HetNets Complexity

Because they are touted for 5G, we must mention the "heterogeneous network" configurations or "HetNets" being contemplated. Development is in the works today to permit multiple channels among the same or even different frequency bands to be concatenated, carrying additive portions of a user's data simultaneously. An example would be an emerging standard called LTE-License Assisted Access,[35] which will concatenate the use of a conventional, licensed cellular LTE channel with LTE deployed on the 5 GHz unlicensed band for best-effort overflow, to the extent the unlicensed channel may be unimpaired and have capacity at the moment. Other standards are in development that would concatenate completely separate technologies among bands, such as Licensed Wireless Access, that would concatenate use of LTE on licensed spectra and Wi-Fi on unlicensed. All of these, of course, could provide more broadband simply by adding up the capacity of individual streams. However there are enormous complexities to interworking and reconciling these dissimilar *and competing* networks and standards, which are anticipated to be pre-5G propositions – nothing upon which one should stake a long term, publicly funded commitment, until mmW bands and devices that can handle them finally begin to become ubiquitously and globally standardized, licensed, with channels auto-managed among users by computer in the case of shared-use spectrum, and generally available for genuine 5G, anticipated for after 2020.

Method 3: Fewer Users Per Cell

The last means of increasing capacity for an entire system is by reducing the number of users per cell. This is accomplished by placing cells closer and closer together, so that the same capacity once afforded to a large coverage footprint of one cell utilizing a radio channel can be applied many times over with multiple, smaller cells in the same coverage footprint, all re-using that same channel. This is nothing new. Since first generation cellular (1G), when cells were on 500 foot towers and tens of miles apart, cells have been getting lower and lower to the ground and closer and closer together, in order to re-use available spectrum to increase capacity. Today, except in sparsely populated rural areas, 4G cells typically are only 100 feet or less off the ground and placed every few blocks in urban areas. 5G's "small cells" are simply a natural evolution of this "cell-splitting" technique. And, as explained below, the laws of physics indeed will necessitate that they be "small."

Shortcomings of Closer Cell Spacing

[35] A competing and largely promoted industry-developed standard to LTE-LAA is LTE-Unlicensed (LTE-U), which particularly Verizon and Qualcomm are committed to trialing in 2017. This of course is being met with fierce resistance by the Wi-Fi Alliance to its potential to overrun the 5 GHz band commonly used for Wi-Fi, which is gaining the attention of the FCC and possibly eventually even Congress.

One cannot improve a system's overall capacity simply by moving the same cells closer together and serving only customers within the cell's higher throughput coverage areas depicted in Figure 4. Managing inter-site distance and coverage overlaps must be planned carefully so as to keep interference to neighboring cells to a minimum, so that, as described in Method 1, capacity can be maintained.

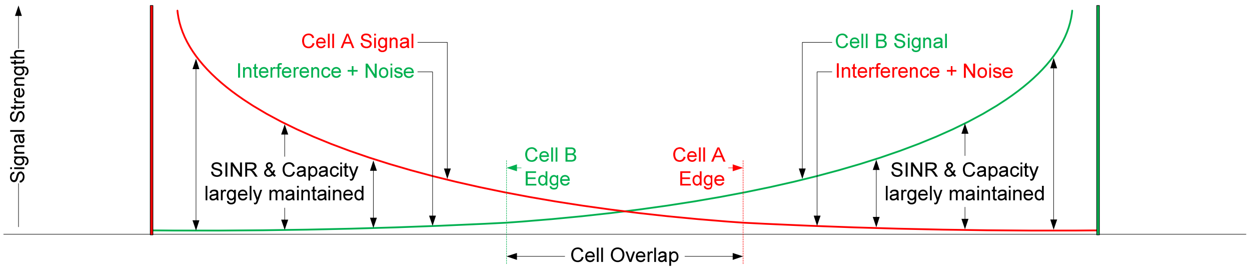

Figure 4 – Minimum Co-Channel Interference for Design Capacity Among Multiple Cells

Signal still propagates from the access point out to the edge of its otherwise usable coverage, whether it is used or not. Therefore, attempts to place cells closer together in this manner, as shown in Figure 5, will only reduce the overall efficiency of the multi-cell system as a whole,[36]

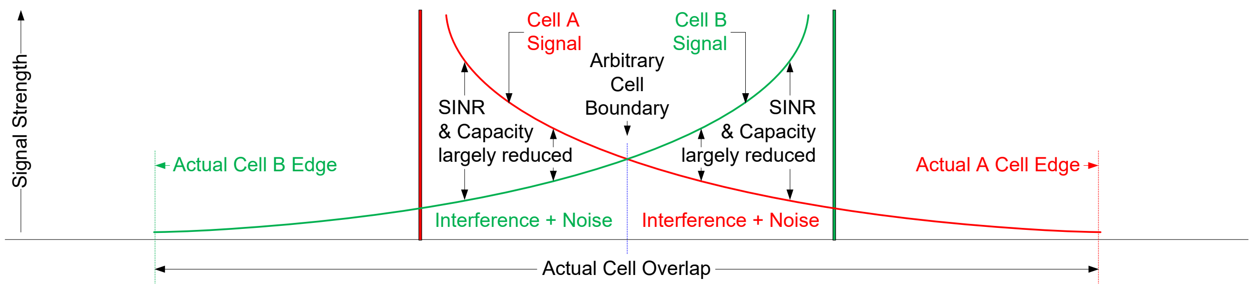

Figure 5 – Closer Overlap to Use Only High Modulation Rates Reduces Overall Capacity

It follows that, regardless of technology,[37] to place cells more closely together, signal power must be reduced, either by lowering transmitter powers, antenna elevations, and /or with radical antenna down-tilting, any or all of which result in forcing the cells to be much smaller than they could be as stand-alone, with their capacity footprints shrinking correspondingly, as shown in Figure 6.

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[36] The full expression of cell spectral efficiency by LTE standards body 3GPP indeed takes this into account for a multiple cell system, being defined as the aggregate throughput of all users (the number of correctly received bits over a certain period of time) normalized by the overall cell bandwidth divided by the number of cells, for a given ISD (Inter-Site Distance). For multiple cells, the cell spectral efficiency of the entire system is measured in bps/Hz/cell.

[37] It is true that "4.5G" LTE-Advanced technology is emerging to permit adjacent cells to divvy-up LTE resources (subcarriers and timeslots) within a channel so as not to interfere with one another. But even if this could be deployed today, this simply has the effect of lowering the amount of total spectrum available to each cell, which per Shannon's Law also lowers capacity for each. Another alternative is to resort to frequency re-use patterns greater than R=1, such that neighboring cells are on different frequencies so as not to interfere with each other, as is often done on unlicensed bands. However this does not improve spectral efficiency either, because if the number of channels used is increased, this results in the system-wide spectral efficiency being divided by the number of channels in the re-use pool.

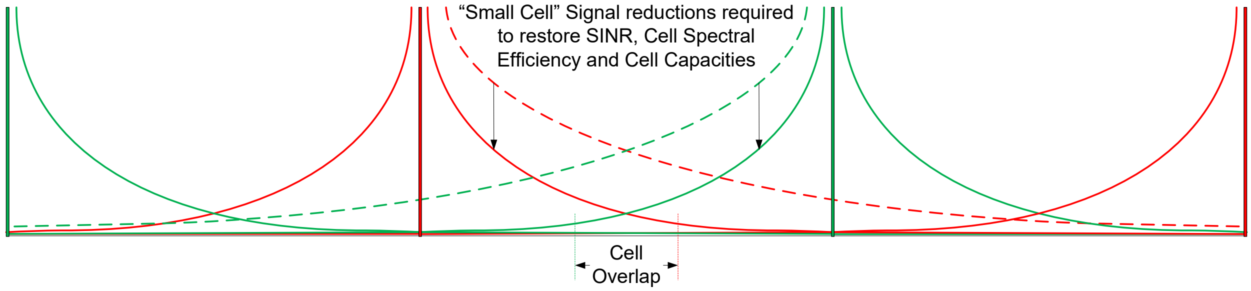

Figure 6 – Closer Co-Channel Spacing Requires Reducing Power, Smaller Cells

<u>Many Additional Cell Densification Challenges</u>

In a 5G network, the resulting small cells indeed will need to be quite small. Moving cells closer together is especially difficult if using currently available sub-6 GHz spectra that propagate "too well" for dense small cell applications. Designs to meet the 5G bandwidth targets, and which also accommodate future mmW ranges, have made their coverage areas typically less than 1,000 feet in diameter, often even half of this, and only 20 or so feet off the ground, with equipment to be deployed on streetlight and utility poles. Some estimates put 5G small cell deployments at ten times the number of sites as their current 4G macro-cell counterparts.

The obvious hurdles to such a dense deployment include the vastly increased need for backhaul for so many cells so close together, particularly the dark fiber-optic cable required for "fronthaul"[38] by most current configuration designs. All of these sites also will need power. Both of these can be exceedingly difficult to coordinate and accomplish.

There are other issues to consider and confront as well in assessing and validating the ability of a potential/proposed 5G wireless deployment to deliver on the promise of high-speed, high-capacity coverage. User devices will have to incorporate many bands, and with vastly expanded MIMO capabilities. This will require software-tunable RF components and antennas, which just now are emerging from labs, plus very capable device processors, none of which is expected to be developed and generally available until after 2020.

[38] The term "small cells" is used herein to refer simply to a general category of tiny coverage area cells. Small cells as a category can include various configurations, most of which require dark fiber for "fronthaul." Today these configuration include Outdoor Distributed Antenna Systems (O-DAS), Centralized - Radio Access Networks (C-RAN) and virtualized Radio Access Network (vRAN). All of these have some or all parts of the access point base station centralized, where it is backhauled to the Core network typically via Carrier Ethernet over some medium, fiber, wireless or otherwise, but with dark fiber then required from the centralized electronics to Remote Radio Units (RRUs) at the antennas. Ironically, none of these configurations technically are true "small cells." A true "small cell" has all access point electronics in one place at the antenna locations, which are backhauled directly to the Core network typically via Carrier Ethernet over some medium.

Does 5G Have Enough Capacity?

A 5G Capacity Example

Let's assume that 5G one day will be able to achieve its goal of 100x current 4G peak data rate capability, as much as 10 Gbps peak data rate per small cell. Applying the practical cell throughput factor developed previously of around 15%, this falls to around 1.5 Gbps of likely actual usable throughput available per cell, to be shared among all users.

1.5 Gbps, even to be shared, certainly might seem like a lot today, when compared to today's typical broadband speed of around 41 Mbps, as discussed previously. But we need to remember that the 5G technologies explored here will only be generally available after 2020. As further discussed in this paper, it is reasonable to expect that median broadband speed will be approaching 100-150 Mbps by that time, and will be 1 Gbps by the 5G equipment end of life if it were installed in 2020. And it certainly is reasonable to expect that 1 Gbps broadband service tiers will be commonplace by 2020, as they are desirable and subscribed to even today. Demonstrating this, the FCC requires applications for CAF Phase II funding via competitive bidding to select the tier for which they are applying and competing, which includes a 1 Gbps tier, as shown in Figure 7.[39]

Performance Tier	Speed	Usage Allowance
Minimum	≥ 10/1 Mbps	≥150 GB
Baseline	≥25/3 Mbps	≥150 GB or U.S. median, whichever is higher
Above Baseline	≥100/20 Mbps	Unlimited
Gigabit	≥1 Gbps/500 Mbps	Unlimited

Figure 7 – FCC-Adopted Broadband Performance Tiers for CAF Phase II Funding

The above further brings to light the notion of monthly usage volume, and its bearing on service quality. Wireless carriers commonly have had to limit monthly usage as a means to limit oversubscribing of their shared broadband resource. This however has not been typical of wireline and particularly FTTH providers – those generally being the only ones that can offer higher than 100 Mbps service tiers today.

Oversubscription Increasingly Precluded for Shared Wireless Resources

Primarily IP video, which is critical distance learning, telemedicine, entertainment and other purposes, is driving a need to limit oversubscription of shared broadband resources such as that

[39] In the Matter of Connect America Fund ETC Annual Reports and Certifications Rural Broadband Experiments, FCC 16-64, Report and Order and Further Notice of Proposed Rulemaking, released May 26, 2016, page 9. (https://apps.fcc.gov/edocs_public/attachmatch/FCC-16-64A1.pdf)

of wireless today. In days when bursty web-browsing traffic dominated Internet, broadband capacity could be significantly oversubscribed. High-volume data streams (such as video), on the other hand, require constant bit rates. This largely undermines, if not defeats, any ability to oversubscribe a resource among active users. Increasingly, this has resulted in only the probability of the percentage of subscribers being active vs. not active during busy hours, based empirically on their observed behavior, as the sole basis for any possible oversubscription. Dimensioning system capacity based on this can be risky business, and especially with video, can easily lead to serious cell congestion with any heavier than normal activity.

From the experience of Vantage Point's clients with fixed wireless operations, without limiting measures, most are finding it difficult to oversubscribe access point capacity (based on cell spectral efficiency) by more than 5:1 today, and some are having to resort to non-discriminatory, across-the-board video train-up limiting measures.[40] This situation will only worsen as data demands, including but not limited to IP video traffic, grow as projected by Cisco and others.

So how can 5G be expected to perform in meeting this demand? If 1 Gbps is a reasonable household broadband service expectation within the 5G equipment's service life, then *tomorrow's* maximum 5G small cell throughput cell capacity expectation on the order of 1.5 Gbps for that timeframe – to be shared among all users, and which may seem plentiful today -- will be a mediocre if not very poor solution for *tomorrow's* fixed broadband. If subscribers' on-line vs. off-line behavior of tomorrow mirrors today's, and if an oversubscription rate of 5:1 can be maintained for 100-150 Mbps median service in 2020, then it would appear that a best-possible-case 5G small cell may be able to serve as many as 10-15 households. However, if only two users are active with a video or other, likely constant-bit-rate application requiring 1 Gbps, then the small cell is in danger of serious congestion, and/or will require throughput limiting - either of which will render it indeed a mediocre if not very poor solution.

What Can 5G Do For Rural?

The extreme densification and short-haul small cell ranges that will be necessary to achieve 5G generally will make it usable only in dense urban scenarios. This becomes obvious when observing Figure 8, depicting the real-world geographic limitations for small cells in rural environments. Assuming a typical 500 foot coverage radius for small cells, this amounts to approximately 0.03 square miles of coverage for each.

[40] Many are having to resort to platforms that limit all video streaming applications in a non-discriminatory fashion from initially training-up to any high-definition throughput rates, in order to keep access points from being hopelessly congested by video accessed by only a very small number of households per access point, and to realize any kind of deployment cost-effectiveness. For their subscribers, though, the result of not being able to stream HD or UHD streams, as their wireline counterpart subscribers can today, indeed makes for a comparatively mediocre wireless broadband experience.

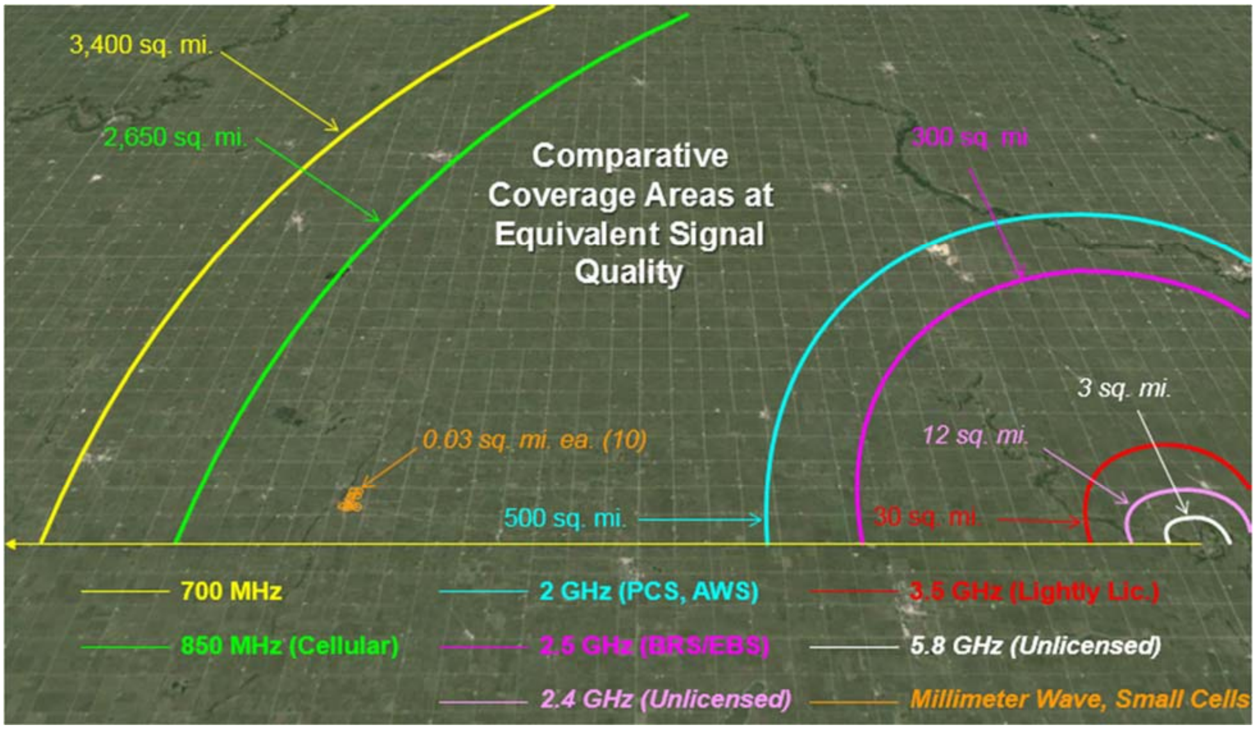

Figure 8 – Spectrum vs. Range Comparison
(Permitted power per FCC service rules assumed per band) [41]

For rural America, where the digital divide is most commonplace today and requires the most effort to overcome, it becomes clear that 5G wireless will not be viable on a widespread basis outside of towns with reasonably dense, relatively compactly-settled populations. Unless perhaps a case may exist where the cost of updating a macro site with "4.5G" LTE[42] to serve a *very* few households requiring sophisticated, multi-band CPE over a large geography is less than the cost of fiber deployment, it is clear that for closing the digital divide, 5G small cells, if considered for any sort of "Wireless to The Home" ("WTTH") deployment, offer limited promise at best as a widespread solution to rural broadband challenges.

To be clear again, this is not to say that 5G does not have an important role in discrete cases or applications as a complement to fiber or as part of a diverse network deployment strategy that leverages both fiber and wireless technologies to drive broadband deeper into rural areas. For mobile services in particular, 5G promises a significant revolution. But the realities discussed in this section make clear that if 5G wireless is going to deliver on the claims of high speeds and

[41] This is intended only to suggest relative ranges and coverage areas among various single carrier frequencies at a common Receive Signal Level (RSL) and noise floor throughout, which may be above or below the lowest RSL at which a particular technology can operate, assuming sufficient SINR. Actual range will vary depending upon the actual signal level and quality targeted as well as numerous other factors, including power level transmitted, elevation of transmitter and receiver antennas, directionality, gain and MIMO configuration of both the transmitting and receiving antennas, terrain, clutter, manmade interference and atmospheric and electromagnetic conditions, among others.
[42] Such as, Multi-User (beam-forming) MIMO and concatenation of several non-contiguous channels in sub-6 GHz frequency bands

high capacity that many hope, it will need to be a “deep fiber” network that is very similar to FTTH in fact. Even if we were to consider 5G wireless in a sort of “WTTH” deployment for rural communities, and, even if 5G capacity somehow could be achieved that could render small cells sufficient for meeting multiple households’ projected demands, it is unclear why, when one is putting fiber *so* deep into the network to enable such speeds and to overcome the capacity constraints identified in this paper, one would stop at the small cell rather than just delivering fiber to the premises a few hundred feet away – and thereby deliver the promise of much higher speeds and availability without the same kinds of capacity limitations.

Assessing the Economics of 5G Wireless Deployments

Fiber optic networks have significantly more broadband capabilities than wireless networks. This will not change in the future. Unlike wireless networks, fiber optic communications do not suffer from line-of-sight issues, obstacles, environmental effects or electromagnetic interference. To increase broadband capacity and reliability, nearly all broadband providers – both wireline and wireless – are replacing much or all of their copper and wireless networks with fiber. The broadband speed and capacity of wireless networks are increasing as more and more of their network is replaced with fiber. The remaining wireless portions of the network introduce a broadband bottleneck.

To minimize the broadband bottleneck in their networks, as discussed above, wireless carriers are already minimizing – and will need to redouble their efforts to minimize in the future – the wireless portion of their networks by placing towers closer and closer to their customers. As described previously, future 5G wireless networks will only use wireless in a small portion of the network - probably the last 300-500 feet of the network. When constructing a broadband network, one may consider a 5G network where fiber is run to within 300-500 feet of the customer premises or simply run fiber all the way to the customer in a FTTP network. We will discuss the economics of these approaches in the following sections.

The economics of a broadband deployment in a "town" environment is very different than the economics of a deployment in a "country" rural environment, so we discuss these separately. In the following section we focus on the local loop investment costs. However, it should be noted that the cost for the central office electronics for the 4G network has historically been considerably more than the central office costs associated with a FTTP network. Since the cost for a 5G core network electronics are still not well defined, these costs have not been considered, but could significantly increase the cost estimates for the 5G wireless network below.

Town Capital Expenditure (CapEx) Considerations

For town deployments, a 5G cell could be placed on a small tower or pole such that 8-12 homes would be reachable within 300-500 feet. This pole could be in an alleyway or located on the street using a light pole or other structure. In a 5G wireless network, this cell is served by fiber from an electronics location either in a central office or cabinet. This architecture is not unlike the FTTP network where the last pedestal is connected by fiber back to the central office (or cabinet) and may also serve 8-12 customers. The primary difference is the "customer drop" or simply the "drop." The drop is the last connection into the customer premises. For the 5G network, the drop is a radio frequency (RF) signal from the pole and for a FTTP network, it is a fiber optic cable from the last pedestal.

The cost to construct fiber from the central office to the pole for the 5G cell would be similar to the cost of constructing fiber from the central office to the last pedestal in a FTTP network. The differences in cost would be primarily in the last 300-500 feet (i.e., the drop). In addition to the fiber drop and wireless drop, the customer premises also requires some electronics to convert the fiber signal or radio frequency signal to something usable to the customer, such as an Ethernet connection.

The cost for FTTP electronics (the ONT), the battery backup, grounding and installation is commonly $760. Similar to the FTTP network, the wireless network would also require a battery backup, electronics, and grounding at the customer premises. The wireless electronics converts the radio frequency to Ethernet (or Wi-Fi). Since the higher frequencies used for the 5G networks do not penetrate obstacles, a pole may need to be installed to avoid trees or other buildings. Because of this, the wireless electronics is often more expensive than the FTTP electronics. Tree cover and other factors can dramatically increase the cost of the 5G electronics installation at the customer location.

The cost for materials and labor to install a fiber drop is typically $5 per foot (for buried or aerial). Since the average fiber drop length in a town environment is 160 feet, the cost is typically $800 per customer. Therefore, the cost to install fiber drops to all 8-12 customers on a city block would range from $6,000 to $10,000. A small tower and 5G cell site would cost $30,000-$50,000. The cell site would also require commercial power and batteries if the wireless network were expected to work during a power outage.

For 5G wireless, it appears that the customer premises electronics are at least as much as the FTTP electronics and likely more expensive. The drop cost for the FTTP network is likely 25% of the cost of the 5G wireless drop. Also considering that the FTTP network can deliver more than 100 times the speed and capacity of the 5G wireless network, it appears that the FTTP is a considerably better value if fixed broadband is the goal with the assumptions above.

Rural CapEx Considerations

In rural areas, the density of customers is measured in customers per square mile, not customers per city block. For a 5G wireless network with a wireless drop length of only 500 feet, this would result in each customer having their own serving cell site. Therefore, the cost for the tower and electronics could not be spread across 8-12 customers as was done in the town example. It would cost $30,000-$50,000 per customer for the cell site alone. The fiber drop in a rural environment is longer (may be 500 feet on average). A 500 foot drop that costs $5 per foot to install could cost $2,500. Even though this drop cost is more than the town environment, it is obviously far less than the cost to install a 5G cell site to serve this single customer.

Operational Expense (OpEx) Considerations

Apart from the initial capital expense advantage that the FTTP network appears to have, it likely also has operational expense savings. Some of these include:

- Customer Premises Electronics – Both FTTP and the 5G networks have electronics and a battery at the customer premises. However, it would be expected that the FTTP electronics would have a longer useful life simply due to the fact that the broadband capability is more than 100 time greater for the FTTP when compared to the 5G network.
- Equipment Maintenance – The wireless network has an external antenna that requires careful alignment and can become misaligned during a windstorm or could be obstructed by the growth of a tree.
- Utility Costs – The 5G wireless solution requires commercial power at every cell site. If each cell site serves, on average, 10 locations there would be 2,000 cell sites in a town with 20,000 locations. Each of these would not only incur the initial cost of installing commercial power, but would also have a monthly recurring cost. The FTTP network is completely passive between the central office and the customer premises and requires no power.
- Replacement Cost – The 5G wireless local loop uses electronics that would normally depreciate over 7 years. The FTTP local loop uses fiber optic cable that depreciates over 20-30 years. Even with higher loop costs for the 5G wireless network, it would likely need to be replace three times during the life of the FTTP loop, which would increase the cost even more.

As the 5G wireless network is more expensive for the initial CapEx as well as the OpEx and provides 1% of the broadband speed and capacity available on a FTTP network, it does not appear that it would generally be a good investment if being used only for fixed broadband services. It is possible that there could be some select scenarios for which it may make economic sense, but one would expect those scenarios would be limited.

So the conclusion drawn in Vantage Point's March 2015 paper still holds: "Wireless networks are needed for low bit rate mobile applications, such as voice, email and small screen video. In contrast, wireline networks are required to meet customers' high speed, fixed broadband needs. As demonstrated in this report, for most customers, wireless technologies will not be a replacement for, but rather a complement to, wireline broadband technologies."[43]

[43] Wireless Broadband is Not a Viable Substitute for Wireline Broadband, Vantage Point Solutions, March 2015, pg. 3 (http://www.ntca.org/images/stories/Documents/fixedwirelesswhitepaper.pdf)

Considerations When Evaluating a Wireless Network

As discussed in this paper, it is necessary to understand within the context of each proposed deployment what a proposed 5G solution really can – and cannot – achieve, especially if we are to consider if it will be the best use of limited investment resources for meeting current and anticipated demand growth over the life of the network assets. With this in mind, the following, at the minimum, must be fully vetted when considering any 5G proposal, and for *each* technology of what could be several being networked together into any sort of proposed "HetNet" solution:

1. For the air interface technology being proposed, what is the service life of the equipment?
    a. Radio Access Network (RAN)?
    b. Customer Premises Equipment (CPE)?
2. What are the proposed service tier(s):
    a. For the initial deployment?
    b. Anticipated to be required within the service life of the equipment?
3. Will monthly usage volume be unlimited, or are usage limits proposed?
4. What air interface technology is being proposed?
5. Is the air interface technology being proposed:
    a. Standardized by a global standards body?
        i. If so, specify
    b. Or is the solution being proposed an industry-driven "standard"?
        i. If so, specify
    c. Or is the solution being proposed vendor proprietary?
6. What are the proposed:
    a. Spectrum band(s) of operation?
    b. Channelization and channel bandwidth(s)?
7. Can channels in the proposed solution be re-used in every cell [*i.e.,* Re-use factor (R)=1]?
    a. If R>1, what is R, and what is the channel re-use plan?
8. What are the proposed:
    a. Power levels?
    b. Modulation techniques?
    c. MIMO methods and Matrices?
    d. Receiver sensitivity and SINR required for each?
9. What will the proposed cell spacing [Inter-Site Distance (ISD)] be?
10. What is the spectral efficiency of the proposed technology (bps/Hz)?
    a. Peak?
    b. Cell average?
    c. Is the ratio of b) to a) realistic?
    d. How are the above being used in calculations by the solution provider for providing the proposed capacity to be shared among subscribers?
11. Will the proposed solution be dedicated 100% to fixed broadband service, or will it also be used for mobile?
    a. If the latter, and if fixed operations are not to receive 100% priority, how will the cell capacity be partitioned or otherwise shared between fixed and mobile?

i. What diminished percentage of cell capacity shall result for fixed operations?

12. Is there a Modulation and Coding Scheme (MCS) level below which service will be refused?
13. Has an RF model been provided, graduated to show the extent of coverage that can support:
    a. Initially proposed service tiers? (*e.g.,* 100 Mbps?)
    b. Anticipated service tiers within the service life of equipment? (*e.g.,* 1 Gbps?)
14. Have sufficiently granular terrain data and clutter morphology been incorporated and resulting Non-Line Of Site (NLOS) losses accounted for in the RF model?
15. Does the coverage reflected by the RF model represent only the extent that an advertised speed is possible for a single user, or does it incorporate multiple user loading?
16. What is the number of households and business locations proposed to be covered and served per small cell at the tier speeds proposed?
    a. Has geo-coded location data been provided to support this?
17. What is the proposed or resulting oversubscription rate, derived from the product of the number of locations proposed to be covered and taking service times their proposed service tier speed(s), compared to the realistic overall cell capacity (derived from the practical cell spectral efficiency):
    a. Initially proposed service tiers? (*e.g.,* at 100 Mbps?)
    b. Anticipated service tiers within the service life of equipment? (*e.g.,* at 1 Gbps?)
18. What methodology is proposed to handle congestion of the shared wireless resource when a higher number of active users than planned for oversubscription access the service?
19. Is any sort of across-the-board application limiting proposed that would ubiquitously limit a subscriber's experience to less than the subscriber's tier's advertised speed?
20. Are high median-to-advertised speed percentages that are comparable to wireline broadband services reasonable to expect from the shared wireless broadband resource, from the above calculations and methods:
    a. Initially proposed service tiers? (*e.g.,* at 100 Mbps?)
    b. Anticipated service tiers within the service life of equipment? (*e.g.,* at 1 Gbps?)
21. Is the spectrum being proposed for the solution fully licensed spectrum, and has evidence been submitted to support the applicant's control of it?
22. If any spectrum being proposed is not fully licensed (*i.e.,* shared), what portion of the spectrum proposed for the solution must be shared?
23. For any proposed spectrum that must be shared, to what extent is it shared today:
    a. If it is "Lightly Licensed" (*e.g.,* CBRS)?
    b. If it is Unlicensed?
    c. Has evidence been provided supporting the above?
24. For any proposed spectrum that must be shared, how is spectrum in same geographical coverage areas divided among providers that will share it?
    a. By whom?
    b. Does any such sharing methodology limit the maximum bandwidth of channels?
    c. To what extent can channels be concatenated (if any)?

25. Does the proposed solution rely on (intra-band, intra-technology) channel concatenation?
26. For any proposed spectrum that must be shared and is not divided among providers, (*e.g.,* unlicensed spectra), how is contention for use of the same channels at the same time managed?
    a. By whom?
    b. Or is co-channel sharing mutually deleterious?
27. For any proposed spectrum that must be shared in *any* fashion, what provisions have been made in the proposed solution to account for the reduction in capacity that will result from lack of full-time availability of it?
28. For the spectrum band(s) being proposed, are the channel bandwidths being proposed reasonably available per current FCC rules?
29. Do the channels and channel bandwidths being proposed comply with global standards body band classes and channelizations?
    a. If only an industry-driven "standard" and/or vendor proprietary, can the proposed solution be reconciled with global standards body standards?
30. Has evidence been provided to show that RAN equipment that will support the technology being proposed is generally available for the speeds being claimed?
31. Has evidence been provided to show that CPE that will support the technology being proposed is generally available for the speeds being claimed?
    a. Does such CPE support the CPE category required by the technology, MIMO configurations, MCS levels, any/all frequency bands and channel concatenation required, etc. that is necessary to support the proposed services?
    b. Is such CPE global standards-compliant (*i.e.,* can it be acquired from any of a number of vendors), or is it vendor-proprietary?
        i. If vendor-proprietary, what is the longevity to date and anticipated longevity and wherewithal of the vendor to support the solution for the future?
    c. Can CPE be firmware-upgraded "over-the-air," or at what point in its technology evolution is replacement required?
    d. What is the projected timeframe for replacement requirement due to technology update if it is less than its service life?
32. Is the extent of the physical RAN installation that is necessary for the speeds being claimed reasonable?
33. Is the extent of the physical CPE installation that is necessary for the speeds being claimed reasonable?
34. What is the proposed RAN backhaul/fronthaul methodology?
    a. Is it reasonable for the territory for which the solution is intended?
35. Is it reasonable to expect that local permitting required for the proposed deployment can be obtained in a reasonable timeframe?
    a. Has evidence been provided to support this?