5G Is Not the Answer For Rural Broadband

5G wireless, due to begin rolling out in 2020, will improve mobile broadband and support the internet of things. It may even be suitable for fixed broadband in dense urban areas. But it has neither the capacity nor the cost-effectiveness to address the rural fixed broadband gap.

By Larry Thompson and Warren Vande Stadt / *Vantage Point Solutions*

Much has been written about the phenomenal speeds that fifth-generation (5G) wireless networks will support. Policymakers have speculated that 5G wireless will solve the rural broadband gap and make fiber to the home obsolete.

In fact, though 5G may represent substantial progress, particularly in the context of mobile service, it is more evolutionary than revolutionary. It is targeted primarily at, and is most effective in, densely populated areas. It is also suitable for the very low-demand, very occasional-use sensors and actuators that will proliferate with the forthcoming internet of things (IoT). But because 5G depends on very densely deployed small cells, it is highly unlikely to replace 4G for coverage outside towns and thus will not be a solution for the digital divide that affects those areas. Even within rural community centers, its requirement of "deep fiber" renders it unlikely to be cost-effective for fixed broadband, and it potentially bottlenecks the service at the same time, compared with fiber to the premises (FTTP).

THE FUTURE OF BROADBAND DEMAND

The internet connects people and machines throughout the world and has changed the ways people communicate, educate, provide health care, and buy and sell goods. E-commerce, social media, video communications and video streaming are taken for granted today. The IoT, smart-grid and smart-city applications, cloud computing, distance learning and telemedicine are only in nascent stages of anticipated exponential growth.

Many broadband drivers, including distance learning, remote telemedicine, video conferencing and entertainment, involve the delivery of video over the internet. Cisco believes IP video traffic will account for 82 percent of internet traffic by 2020. This is significant because some network technologies are better suited than others for delivering continuous-bit-rate applications such as video. Networks that dedicate capacity to each customer, as most landline copper and fiber technologies do, are better suited to deliver this type of traffic than networks that share capacity among many users, such as wireless networks. Delivering video to a customer continuously for a two-hour movie on a wireless network means that capacity is not available during this time for another user.

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. Tom Rutledge, chairman and CEO of Charter Communications, has said that the cable operator is “moving toward a future where broadband speeds of up to 10 gigabits per second are possible.” Verizon now offers a 750 Mbps tier in its Fios markets in New York City, New Jersey, Philadelphia and Boston. AT&T offers gigabit services in many of its markets and plans to add many more, and Comcast is offering a 2 Gbps service in many of its markets. Google Fiber offers 1 Gbps in several cities today.

Nielsen’s Law, posited by Jakob Nielsen in 1998, states that broadband bandwidth demand grows at a rate of 50 percent a year for high-end users. The broadband connection experience over the years supports his theory. Projecting current trends into the future suggests that 1 Gbps connections will be commonly available before 2020.

Median broadband speed, which is less than what is “commonly available,” was 41 Mbps in September 2015, an increase of 28 percent over the previous year’s median speed of 32 Mbps. If the growth rate continues at 28 percent annually, the median speed will be 100–150 Mbps in 2020, when 5G networks become available, and 1 Gbps at the 5G equipment’s end of life eight years later.

CAN 5G MEET BANDWIDTH DEMANDS?

5G has been touted to provide speeds 100 times faster than 4G wireless – as high as 10 Gbps – with latency approaching that of fiber. These speeds indeed sound fantastic! But this projection assumes unrealistic conditions and overlooks the critical fact that the capacity must be shared among multiple users.

Wireless vendors often promote their products by listing the fastest data connection rates possible. However, these are theoretical rates possible only in a lab environment and only for a single user located very close to an access point and able to utilize every one of the best-case, unimpaired radio channel resources. This is completely unrealistic for real-world dimensioning for capacity, and it overstates an access point’s practical capacity by 500 percent or more.

> Actual throughput capacity for wireless users is often only 15 percent of the peak data connection rate – although the peak rate is the speed that providers promote.

An access point cannot deliver peak speeds across its entire coverage area, or cell. The quality of a radio channel, its spectral efficiency (bits per second per hertz) and its data rate ability deteriorate rapidly with distance, falling to half or less of peak at only 25 percent of the distance to the cell edge. This represents roughly only 6 percent of the cell.

To determine a cell’s overall practical capacity for broadband, and thus to evaluate the real capability of any proposed network that leverages wireless technology, one must consider the average of the experience among all users near and far. This is often only 15–25 percent of the theoretical peak for a single user. When overheads are considered, the usable capacity will typically be less than 75 percent of this value. It therefore is not unusual for the actual throughput capacity to be only roughly 15 percent of its peak data connection rate – although the latter is the speed that is usually promoted.

THREE WAYS TO GET MORE BROADBAND

Physics limits the evolution of any wireless technology to three methods: increasing transmit power (or reducing noise), adding spectrum and reducing the number of users per cell.

Increasing transmit power or reducing noise. Increasing signal level or reducing noise, including interference, enables better modulation techniques. FCC rules do not permit signal levels (transmitter powers) to increase, and noise will only get worse as more and more transmitters are installed. Without improvement in the ratio of signal to the sum of interference plus noise (SINR), higher efficiency modulation techniques will be usable by only a very few users in each cell, very close to the access point.

Providers that use the sub-6 GHz unlicensed bands to offer fixed broadband service today are painfully aware of this. Even with wider channel bandwidths available, they already struggle to support more than just a few subscribers per access point, even at today’s fixed broadband users’ demand levels, because of the increasing use of video and the uncontrollable and rising noise floor in unlicensed spectra. This will only worsen as the use of Wi-Fi for last-few-feet access by portable devices increases, and as “HetNets,” discussed later, emerge. With little or no additional sub-6 GHz unlicensed spectra becoming available, and with SINR only worsening, attempts to increase capacity with higher modulation rates will only shorten cell ranges further, as explained later.

For all these reasons, sub-6 GHz unlicensed access points, even if they attempt to use “5G-like” techniques, whether standardized or proprietary, will struggle and likely fall further behind in trying to meet tomorrow’s fixed broadband demands in all but the most remote, sparsely used, short-haul applications. In addition, systems that use any unlicensed spectrum are susceptible to being seriously debilitated by competing systems, which can appear close by without warning and without FCC recourse. This renders them risky choices for delivery of any 5G-like fixed broadband, especially if publicly funded. Any significant improvement in wireless broadband performance, then, must be accomplished by adding more spectrum in which interference can be rigidly controlled or by reducing the number of users per cell.

Adding spectrum. There is not enough licensed spectrum in the sub-6 GHz bands that traditional 4G sites use today to facilitate larger channel bandwidths. Although some licensed spectrum has been added with the 600 MHz auction, it is only a tiny fraction of what is required to support the 100x improvement requirement for 5G.

The quantity of licensed or rigidly controlled shared spectrum for mobile broadband is slated to improve in the next few years, however. As a result of its "Spectrum Frontiers" vote on July 14, 2016, the FCC intends to release and repurpose for mobile broadband 18 GHz of so-called millimeter-wave (mmW) spectrum – very, very high frequencies (6 GHz to 80 GHz) whose wavelengths are measured in millimeters rather than meters. But these bands have always been available for fixed broadband (some, such as 39 GHz and 80 GHz, only for point-to-point), and to date, they have gone largely unused for this purpose, for good reason.

The higher the frequency of radio spectrum, the less propagation and penetration power it has. Frequencies this high can propagate only to very short distances before decaying to unusable levels. In addition, they are highly susceptible to fading because of diffraction by rain and moisture and even absorption by oxygen molecules. The result is that the usable, reliable range of high frequencies – even on a clear day – is measured in hundreds of feet, not in miles. This, along with the fact that high frequencies do not penetrate buildings or other obstacles, such as foliage, and must have an unobstructed line-of-sight path, renders them of little use for conventional macrocells. For all these reasons, they have not been considered usable to date for fixed broadband.

As networks must be densified into smaller and smaller cells to increase capacity by the other means discussed below, however, mmW spectrum will become of increasing use. Even though this may be of great benefit to outdoor-to-outdoor or indoor-to-indoor mobility, small cells will be suitable for fixed broadband only in dense, urban environments, if at all. Even then, practically, the cells will connect only to outdoor customer premises equipment, not directly to indoor equipment.

Some carriers, such as Google Fiber, are considering the use of unlicensed 60 GHz to provide a wireless gigabit service. However, any provider that utilizes this spectrum will be challenged to overcome not only all the issues intrinsic to the spectrum but also all those that attend any unlicensed spectrum.

Within its tiny range, mmW spectrum will have available channel widths on the order of 10 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?

Reusing a frequency in the same place at the same time can give the appearance of more spectrum quantity. In fact, this already is being done with the use of multiple input, multiple output (MIMO) air interfaces. But spectrum reuse comes with diminishing returns.

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

Advanced forms of MIMO called multiser 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 user with capacity that approaches what an otherwise conventional site might support in total, and the beams will not interfere much with one another. But again, the improvement in overall throughput goes up only by small fractions of peak theoretical rates.

Another way to add spectrum is through "heterogeneous network" configurations, or "HetNets," which are being touted for 5G. Development is underway 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 is a standard in development called LTE-License Assisted Access, 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. In the meantime, LTE-Unlicensed, a similar but de facto industry standard developed largely by Qualcomm and Verizon, has just been approved by the FCC. T-Mobile intends to implement it immediately to aid in offloading its 4G network. Though useful for wireless carriers, this standard will contribute to overcrowding of the 5 GHz unlicensed band used mostly today for Wi-Fi.

Other standards in development will concatenate completely separate technologies among bands. One example is Licensed Wireless Access, which would concatenate LTE on licensed spectra and Wi-Fi on unlicensed.

All these arrangements, of course, can provide more broadband simply by adding up the capacity of individual streams. However, they are only attempts to render a preliminary, 5G-like experience until frequency-managed and standardized use of

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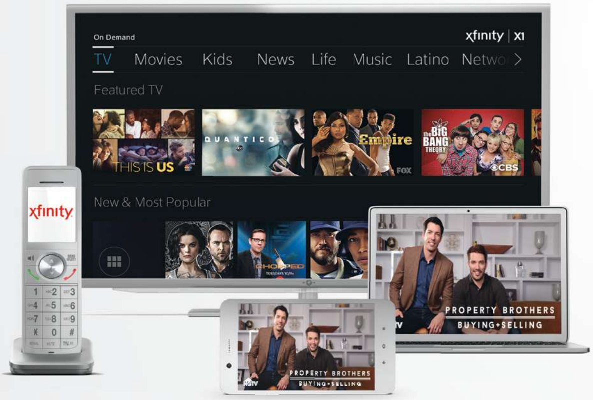

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mmW spectrum for true 5G can be deployed. There are enormous complexities to interworking and reconciling these dissimilar and competing networks and standards, which are anticipated to be pre-5G propositions. No one should stake a long-term, publicly funded commitment on them until after 2020, when mmW bands and devices that can handle them begin to become ubiquitously and globally standardized and licensed, with channels auto-managed among users in the case of shared-use spectrum and generally available for genuine 5G.

Reducing the number of 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 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 reusing that same channel.

This is nothing new. Since first-generation cellular networks, when cells were on 500-foot towers and dozens of miles apart, cells have been placed lower and closer together to reuse available spectrum and increase capacity. Today, 4G cells are typically no more than 100 feet off the ground, except in sparsely populated rural areas, and they are placed every few blocks in urban areas. 5G “small cells” are a natural evolution of this cell-splitting technique. And the laws of physics will indeed necessitate that they be small.

One cannot improve a system’s overall capacity simply by moving the same cells closer together and serving only customers within the cells’ close-in, high-throughput coverage areas, however. Signal still propagates from an access point to the edge of its otherwise usable coverage, whether it is used or not. Attempts to place cells closer together in this manner will raise the noise floor significantly for neighboring cells and reduce the overall efficiency of the multicell system as a whole. Intersite distance and coverage overlaps must be planned carefully to minimize interference to neighboring cells so they can maintain capacity. Placing cells closer together requires reducing signal power by lowering transmitter powers, lowering antenna elevations, and/or tilting antennas radically downward. Any of these strategies forces the cells to be much smaller, shrinking their capacity footprints correspondingly.

In a 5G network, the resulting small cells indeed will need to be quite small. Moving cells closer together is especially difficult if a provider uses currently available sub-6 GHz spectrum that propagates too well for dense small-cell applications. Designs that meet the 5G bandwidth targets and accommodate future mmW ranges have made their coverage areas typically less than 1,000 feet in diameter – often half of this – and placed antennas only about 20 feet off the ground, with equipment deployed on streetlights and utility poles. Some estimates put 5G small-cell deployments at 10 times the number of sites as their current 4G macrocell counterparts.

The 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 that most current configuration designs require for “fronthaul” (connections between base stations and radio antennas). All these sites will also need power. Both can be exceedingly difficult to coordinate and accomplish.

In addition, user devices will have to incorporate many bands and have vastly expanded MIMO capabilities. This will require software-tunable, radio frequency (RF) components and antennas, which are just emerging from labs, plus very capable device processors, none of which are expected to be developed and generally available until after 2020.

DOES 5G HAVE ENOUGH CAPACITY?

Let’s assume that 5G will one day be able to achieve its goal of 10 Gbps peak data rate per small cell. Applying the practical cell throughput factor of around 15 percent, this falls to around 1.5 Gbps of likely actual usable throughput available per cell, shared among all users.

This bandwidth, even shared, might seem like a lot compared with today’s typical broadband speed of around 41 Mbps. But again, it is reasonable to expect median wireline broadband speed to approach 100–150 Mbps by 2020 and 1 Gbps by the 5G equipment end of life. In addition, wireline providers, particularly FTTP providers, typically do not have to limit monthly usage to avoid oversubscribing their shared broadband resources.

Today, IP video drives wireless providers to limit oversubscription of shared broadband resources. IP video is critical for distance learning, telemedicine, entertainment and other purposes. In days when bursty web-browsing traffic dominated the 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 or defeats any ability to oversubscribe a resource among active users.

Increasingly, the only remaining basis for any oversubscription is the likely percentage of active subscribers. Dimensioning system capacity based on forecasts of the number of active users can be risky and easily lead to serious cell congestion if activity is heavier than normal.

Most of Vantage Point’s fixed wireless clients have difficulty oversubscribing access point capacity by more than 5:1 today, and many have had to resort to nondiscriminatory, across-the-board measures to limit video. This situation will only worsen as data demands, including but not limited to IP video traffic, grow as projected by Cisco and others.

If 1 Gbps is a reasonable household broadband service expectation within the 5G equipment’s service life, then the maximum 5G small-cell throughput expectation of about 1.5 Gbps will be a mediocre, if not very poor, solution for tomorrow’s fixed

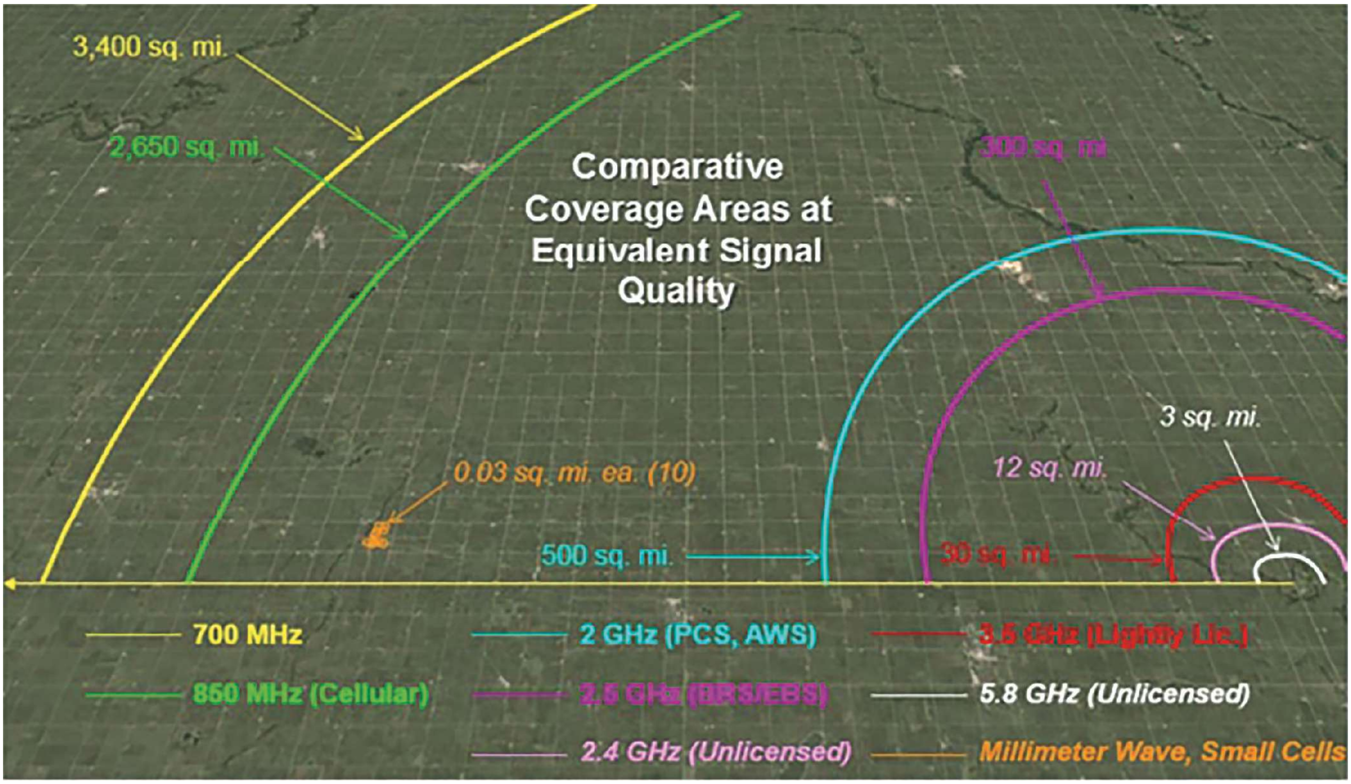

Figure 1 – Spectrum vs. Range (Permitted power per FCC service rules assumed per band)
This figure is intended only to suggest relative ranges and coverage areas among various single-carrier frequencies at a common received signal level (RSL) and noise floor throughout the coverage area, which may be 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.

broadband, with very poor median-to-advertised speed performance.

If subscribers' online versus offline 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-case 5G small cell may be able to serve 10–15 households. However, if just two users are active with a video or another constant-bit-rate application requiring 1 Gbps, the small cell is already in danger of serious congestion and/or will require throughput limiting.

5G IN RURAL AREAS

The extreme densification and short-haul small-cell ranges necessary to achieve 5G generally will make it usable only in dense urban scenarios. Figure 1 depicts 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.

In rural America, where the digital divide is most common today and requires the most effort to overcome, 5G wireless will not be widely viable except possibly in densely populated towns. There may be cases in which the cost of updating a macro site and customer premises equipment with sophisticated, multiband 4.5G LTE electronics and antennas to serve a few households over a large geography is less than the cost of deploying fiber to those households. However, 5G small cells for any sort of "wireless to the home" deployment offer limited promise, at best, as a widespread solution to rural broadband challenges.

5G will still 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 evolution. But to deliver the high speeds and high capacity that many hope for, 5G requires a deep fiber network very similar to FTTP. When one puts fiber so deep into a network, why stop at the small cell rather than at the premises a few hundred feet away? Fiber to the premises allows much higher speeds and availability without the same kinds of capacity limitations.

ASSESSING THE ECONOMICS

Wireless carriers are already minimizing the wireless portion of their networks by placing towers closer and closer to customers. Future 5G wireless networks will probably use wireless only in the last 300–500 feet. That is the scenario we consider here and compare with fiber to the premises.

The cost of central office electronics for a 4G network has historically been considerably more than the central office costs associated with an FTTP network. As the costs for 5G core network electronics are still not well defined, these costs have not been considered, but they could significantly increase the cost estimates for the 5G wireless network below – as could the cost of new spectrum, also not considered.

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

The cost to construct fiber from a central office to a pole for a 5G cell is similar to the cost of constructing fiber from a central office to the last pedestal in an FTTP network. The differences in cost are primarily in the last 300–500 feet (the drop). In addition, the customer premises also requires electronics to convert the fiber signal or RF signal to an Ethernet connection.

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

The cost for materials and labor to install a fiber drop is typically $5 per foot (for buried or aerial). As 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 eight to 12 customers on a city block ranges from $6,000 to $10,000. A small tower and 5G cell site costs $30,000–$50,000. The cell site will also require commercial power and batteries if the wireless network is expected to work during a power outage.

Rural capex considerations. Outside towns, customer density is measured per square mile, not per city block. For a 5G wireless network with a wireless drop length of only 500 feet, each customer will need a dedicated cell site. Therefore, the cost for the tower and electronics cannot be spread across eight to 12 customers as in the town example. The cell site will cost $30,000–$50,000 per customer. The fiber drop in a rural environment is also longer (it 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 in a town environment, it is obviously far less than the cost to install a 5G cell site to serve a single customer.

Opex considerations. Apart from the initial capital expense advantage that FTTP appears to have, it likely also has operational expense savings.

- Customer premises electronics: Although FTTP and the 5G networks both have electronics and a battery at the customer premises, the FTTP electronics likely have a longer useful life because their broadband capability is more than 100 times greater than the 5G electronics.
- Equipment maintenance: The wireless network requires an external antenna that could be obstructed by the growth of a tree or other new structure or that requires careful alignment and can become misaligned during a windstorm.
- Power: A 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 will incur the initial cost of installing commercial power and will 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: A 5G wireless local loop uses electronics that normally depreciate over seven 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, the wireless loop will likely need to be replaced three times during the life of the FTTP loop, which will raise the cost even more.

As the 5G wireless network is more expensive for the initial capex as well as opex and provides 1 percent of the broadband speed and capacity available on an FTTP network, it is unlikely to be a good investment if used only for fixed broadband services. There may be some select scenarios for which it makes economic sense, but one would expect those scenarios to be limited.

So the conclusion initially drawn in Vantage Point's March 2015 paper on 4G 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. For most customers, wireless technologies will not be a replacement for, but rather a complement to, wireline broadband technologies." ❖

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