Comparing Wired And Wireless Broadband

Wireless broadband isn't a complete solution for rural areas but a complement to wireline. The technical limitations of wireless make it an inadequate solution today and prevent it from scaling to meet tomorrow's needs.

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High-quality broadband has become an essential service in urban and rural areas of the United States. According to the FCC, urban and rural users adopt broadband at the same rates where it is available. Education, health care, banking, entertainment and many other industries rely on broadband to deliver their services. As new applications and services are developed, residential and commercial consumers continue to increase their bandwidth demand rapidly.

Broadband providers use a variety of networks based on landline or wireless technologies. Broadband provided over wireless networks unquestionably plays an important role in the lives of consumers today. Many consumers rely on the broadband available on their mobile devices for access to social networks, news, small-screen video and many other applications. Another use of wireless technology is terrestrial fixed wireless, which some believe could be a lower-cost alternative to wireline broadband.

Fixed and mobile wireless networks share many network elements and therefore share many characteristics. Some characteristics of wireless networks limit their utility when used for general-purpose broadband delivery.

A high-quality broadband connection has

- High speed – The network must deliver data at a fast rate.
- Low latency – The network must have a minimal amount of delay.
- High capacity – The network must deliver a quantity of data that meets customers' needs.
- High reliability – The network needs to experience few outages.
- Scalability – The network must be cost-effective to deploy, maintain, and upgrade as broadband demand increases.

Several factors that limit a wireless network's broadband quality do not impact wireline broadband networks. Lack of spectrum limits both speed and capacity. Weather and obstacles such as terrain attenuate wireless signals, limiting availability and reducing reliability. Finally, the speed of a wireless network is a function of the number of users and the proximity of those users to the wireless tower. These factors keep wireless technologies from being economically scalable to higher broadband speeds.

SPECTRUM IS LIMITED

Spectrum is a limited resource and expensive for a wireless carrier to secure. Only a small portion of the available spectrum is available for commercial broadband communications, as depicted in Figure 1. The limited amount of available spectrum significantly constrains the amount of broadband that can be provided, particularly when spectrum is used for the

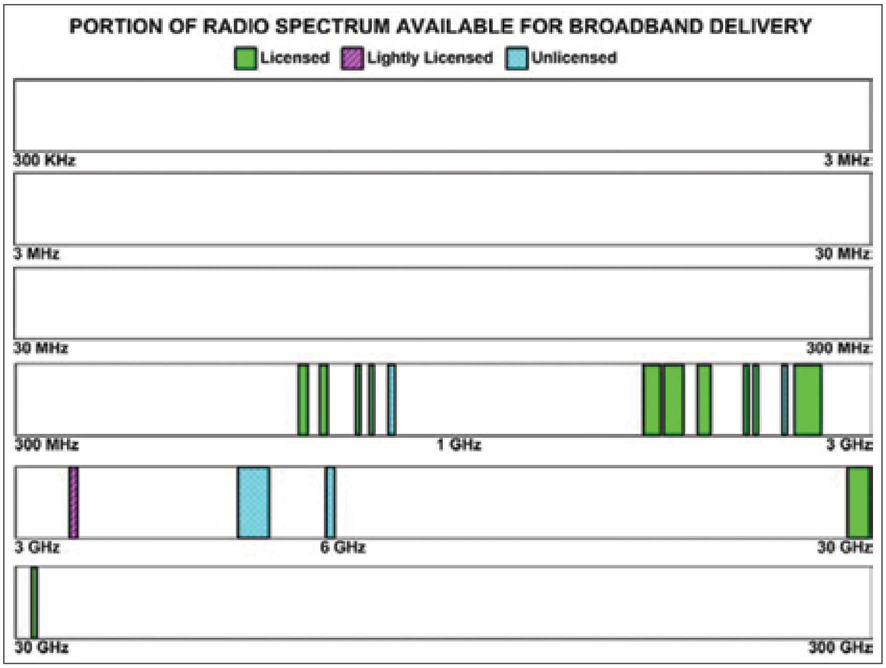

Figure 1: Portion of radio spectrum available for broadband delivery

shared access portion of the wireless network.

For wireless broadband providers that are fortunate enough to have access to spectrum in more than one frequency band, the spectrum is often scattered across various noncontiguous frequency bands, each with unique propagation characteristics. This results in engineering challenges; in addition, there are no wireless technologies available yet that can aggregate the various frequency bands. Small providers typically have only 12 to 20 MHz of spectrum, and larger carriers may be able to afford 50 to 130 MHz of spectrum in some markets. Although 50 to 130 MHz may sound sizable, it is currently inadequate for most urban areas and will be insufficient in rural areas as broadband demand continues to grow.

In its National Broadband Plan, the FCC proposed that 500 MHz of spectrum be made available for broadband, 300 MHz of which was to be made available within five years. Now, five years after the National Broadband Plan, only 65 MHz spectrum has been made available, and no other auctions are planned until early 2016.

The FCC's AWS-3 auction showed that spectrum is in very high demand, and nearly all currently available spectrum has been previously allocated to other uses. Vantage Point Solutions' experience has been that concessions must often be made to existing spectrum holders, and significant expense is often associated with clearing spectrum for broadband uses.

Uncertainties remain as to how much additional spectrum will be made available and when. One thing is clear: Additional spectrum will be expensive if the AWS-3 auction is any indication.

Spectral limitations have a significant impact on the broadband delivery capabilities of a wireless service, as shown in Table 1. The typical speeds shown are the average downstream speed capability. Lower speeds would be achieved at cell edges.

For example, assume a wireless provider holds a 700 MHz license for two 6 MHz channels, one for the upstream and the other for the downstream. If that provider were able to achieve 2 bits per Hz on all 6 MHz, the spectrum could deliver 12 Mbps. Even if this capacity were dedicated to a single customer – which it is not – the available speed and capacity are far less than what is available over most wireline broadband networks. Providing a 100 Mbps symmetrical broadband service, which is commonly offered by wireline providers, would require

Spectrum Name	Typical Contiguous Spectrum Amount (MHz)	Typical Speed Downstream Speed (Mbps)	Typical Distance Cell Edge (Miles)
700 MHz	2 x 6 (FDD)	8.5	20
850 MHz (Cellular)	2 x 10 (FDD)	17	17 ½
2 GHz (PCS and AWS)	2 x 15 (FDD)	26	8
2.5 GHz (BRS/EBS)	1 x 20 (TDD)	21	6 ½

Table 1: Typical spectrum capabilities

1 GHz of spectrum. This amount of spectrum is far greater than any carrier would be able to obtain. The wireless carrier would need to dedicate its entire spectrum to broadband; thus, existing customers, including mobile customers, could not use this spectrum. It would also need to rely on technologies that are not yet available to bond its bands together because the existing spectrum is in noncontiguous bands at different frequencies. Finally, it would have to construct many more towers because only a few customers would exhaust an entire tower's available capacity.

Obviously, these assumptions are unrealistic. Existing wireless customers could not just be abandoned to provide high-speed broadband. Wireless carriers cannot rely on technologies that are not yet commercially available. Constructing a wireless network with many towers, along with the associated other costs such as backhaul, could prove cost prohibitive.

Many wireline providers are beginning to offer gigabit services. For a wireless broadband provider to offer a 1 Gbps symmetrical service, the provider would need the entire spectrum from 1 to 11 GHz – obviously an even more unlikely occurrence.

Further, given that broadband speeds have been increasing by approximately 50 percent per year, even if a wireless network were able to meet customers' broadband needs today, it would be unlikely to meet customers' future broadband needs.

DISTANCE FROM THE ANTENNA REDUCES BROADBAND SPEED

An important determinant of a wireless broadband customer's connection speed is the proximity of that customer to a tower. The farther a customer is from a tower, the lower the signal strength and thus the lower the customer's connection speed. A customer located at the edge of a tower's range may experience more than 60 percent degradation in data rates relative to the average speed for customers closer to the tower. As reflected in Figure 2, Motorola's analysis shows how a customer's broadband

Figure 2: Snapshot of instantaneous user throughput within a typical 10 MHz sector

speed changes as the customer's distance from the provider's antenna increases.

In rural areas, customers may live a long distance from the closest tower, as towers frequently are spaced 10 to 20 miles apart. At this distance, service may be extremely slow or nonexistent. These cell-edge customers decrease the spectral efficiency and thus the throughput capability of the entire cell, so the service of closer-in customers is affected by the presence of cell-edge customers.

A cell coverage area could be shrunk to serve only the closer-in customers that can avail themselves of higher modulation rates. However, this would increase interference for neighboring cells, lowering the neighboring cells' throughput capacity. Thus, except where there are no neighboring systems, this practice would be self-defeating. Even if this practice were not self-defeating, in sparsely populated rural areas there are not enough customers to justify the construction of a large number of towers, which cost between $150,000 and $700,000 each.

WEATHER AND GEOGRAPHY LIMIT WIRELESS AVAILABILITY AND RELIABILITY

Obstacles and weather conditions can degrade or eliminate wireless service altogether. Wireless RF signals used for broadband require a line of sight (LOS) between a transmission tower and a customer. Mountains, hills, buildings and trees interfere with the propagation of the wireless signal. To some extent, LTE can provide non-line-of-sight (NLOS) service, but at significantly reduced throughput compared to direct LOS.

Terrain and obstacle challenges mean that some customers cannot receive a broadband signal unless additional towers are constructed. Moreover, some operating frequencies are highly susceptible to attenuation due to rain, fog or snow, which can also reduce broadband speeds and even cause network outages.

INCREASED NUMBER OF USERS REDUCES WIRELESS BROADBAND SPEED

Because many users link to the same wireless tower, each user's network speed and available capacity declines as more users attempt to use the network. For example, if a carrier controls 20 MHz of spectrum and provides service using 4G LTE (10 MHz for upstream and 10 MHz for downstream), the carrier could potentially deliver 15 to 20 Mbps with some higher-speed bursts. Although these speeds would be barely adequate for a single user based on the FCC's current requirements, this available wireless capacity is shared by all customers serviced in the same sector (that is, by the same access point radio).

A wireless network is a shared access network and is often significantly oversubscribed. Oversubscription works successfully when customers use the network for very short bursts. Increased use of IP video makes it more difficult for shared access networks to continue to meet customer demands. As IP video becomes more commonplace in remote learning, remote medical treatment, communication, social networking and entertainment, individual users will consume larger portions of the access network for longer periods of time. Unless the oversubscription is remedied, customers' network experience will be unsatisfactory.

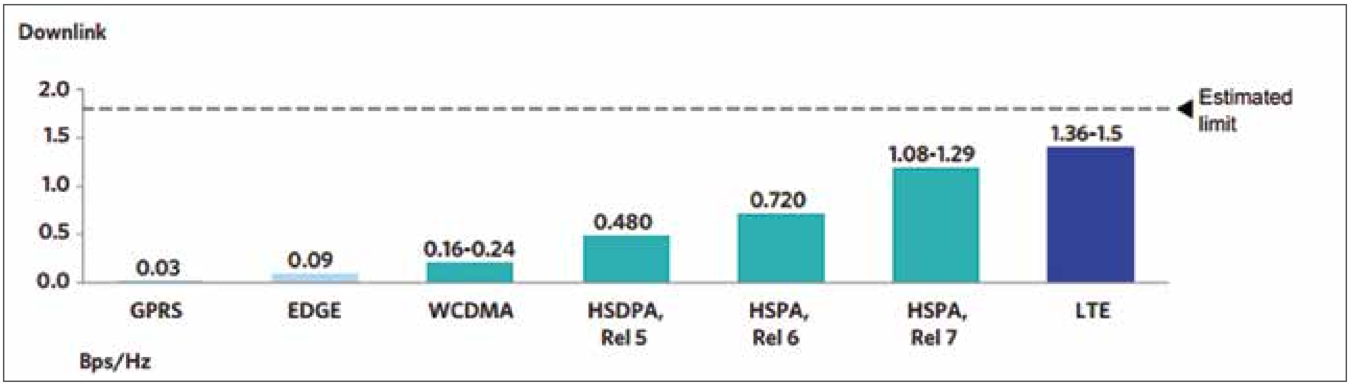

Figure 3: Average spectral efficiency has increased with succeeding wireless standards.

If 100 customers were using the network a the same time, each customer would effectively receive between 150 Kbps and 200 Kbps on average – only a small fraction of the FCC definition of broadband. If two customers were to watch HD videos (typically requiring about 7 Mbps), only 6 Mbps of capacity would be available to the other 98 customers. If a third customer attempted to use a similar service, that customer would likely be blocked. Clearly, such degradation of service would be unacceptable to most customers.

FREQUENCY BAND IMPACTS BROADBAND CAPABILITIES

Spectrum frequency also affects the number of towers required. The higher the frequency, the shorter the propagation distance and penetration ability. Shorter propagation distances require more towers, which raises the cost of a wireless broadband network.

Generally, spectrum up to 6 GHz is best for broadband delivery systems, and spectrum below 1 GHz is optimal for rural areas where there are long distances between consumers and towers. The wireless broadband spectrum available to a carrier is either licensed, lightly licensed or unlicensed.

- Unlicensed Spectrum – Unlicensed wireless technologies use 900 MHz, 2.4 GHz or 5 GHz spectra. Wireless Internet service providers primarily utilize unlicensed or lightly licensed spectra, which they must share with equipment for Wi-Fi, Bluetooth, agricultural GPS telemetry and control, cordless phones, garage door openers, baby monitors, microwave ovens and many more applications. As operators in unlicensed spectra have no legal protection against interference, unlicensed wireless broadband is often used only as an adjunct service to fixed broadband. Some WLAN technologies with peak theoretical speeds up to 1 Gbps are being discussed using unlicensed 60 GHz spectrum. However, the propagation of this frequency is limited to a few meters.
- Lightly Licensed Spectrum – Lightly licensed systems are available for the 3.65 GHz band. This spectrum must be shared with all service providers, no matter which entity deployed its network first. The lightly licensed spectrum requirements oblige users only to register base stations and coordinate with others.
- Licensed Spectrum – Mobile wireless carriers, as well as many fixed wireless carriers, rely on licensed spectrum in the 700 MHz, 850 MHz (cellular), 2 GHz (PCS and AWS) and 2.5 GHz (BRS/EBS) licensed bands. A wireless carrier using licensed frequency bands is protected from other networks' interfering with its broadband signal.

Wireless broadband carriers generally prefer licensed spectrum because it is protected from interference by other carriers and services, but there is a cost to purchase the rights to licensed spectrum. Given unlicensed spectrum's increasing interference problems, providers that utilize unlicensed spectrum will continue to struggle to find wide, unencumbered, contiguous channels to satisfactorily meet customers' ever-increasing bandwidth demands.

INCREASES IN SPECTRAL EFFICIENCY ARE LIMITED

The spectral efficiency of a given technology determines the maximum throughput available per Hz of spectrum bandwidth. In 1948, mathematician Claude Shannon published "A Mathematical Theory of Communication," which has since become an industry standard. Shannon arrived at an equation that describes the relationship of the limiting factors of a communications channel's information transfer rate ability.

In general, for throughput capacity to increase, channel bandwidth must increase or the signal-to-noise ratio must increase. The use of advanced modulation schemes allows future technologies to approach the theoretical limit of spectral efficiency predicted by Shannon's law, 1.5 bps per Hz to 2.0 bps per Hz. Many experts believe that 4G LTE already performs at close to the theoretical limit of spectral efficiency.

According to Shannon's law, increases in signal power increases throughput capability. Increases in signal power would be required in both base-station and end-user equipment to maintain a balanced communication path. However, signal power increases may not be practical for end-user equipment because of limits on device size, battery life, cost and so forth. In addition, signal power increases must be approved by the FCC.

Even if signal power increases were practical, they tend to be self-defeating in point-to-multipoint wireless broadband systems because they also increase the noise level in neighboring sectors – and thus, according to Shannon's law, limit throughput capacity in those sectors. Cellular systems today operate at the optimal balance of signal power and acceptable noise as increases in one necessarily cause penalties in the other.

Cell splitting (the use of smaller cells to reuse frequencies) or other spatial diversity techniques can improve throughput capacity. Spatial diversity techniques, by using multiple paths simultaneously on the same frequency, improve the *apparent* spectral efficiency of a given amount of spectrum. Once the technology evolves, wireless providers could use spatial diversity techniques such as beam-forming, in which isolated beams on the same frequency are directed toward specific users, or they could expand the use of multiple input – multiple output (MIMO) techniques, which use multiple antennas at both the user device and the base station to simultaneously send coded transmissions on the same frequency that are decoded by sophisticated digital signal processors. Today, 2x2 MIMO techniques are common, but in the future, 4X4 or 8X8 MIMO could be used.

Unfortunately, these techniques are usually not economically viable in sparsely populated rural areas because of the increased processing power required and the multiple physical antennas necessary for both the base station and user equipment. Techniques to increase broadband throughput also increase network complexity and cost. Vantage Point Solutions estimates that any benefits will likely be realized only by customers in close proximity to towers.

In short, though fiber technologies can accommodate capacity increases at a reasonable cost, every incremental increase in capacity of a wireless network will always come at a significant cost.

Wireless providers can address the bandwidth challenge in several ways: obtain more spectrum, use spectrum more efficiently, build more towers or impose constraints on their customers. As spectrum is limited and expensive, spectral efficiency is close to its limit, and tower construction is expensive, imposing customer constraints is the only remaining solution.

This is reflected in the strict usage caps that wireless providers place on their customers. In contrast to wireline providers, which have usage caps greater than 250 GB and often have unlimited usage plans, wireless data packages include typical usage caps of between 10 and 30 GB per month with steeply higher rates for higher usage plans.

COMPARING NETWORK COSTS AND CAPABILITIES

A provider wants a network that can offer the most broadband for the least investment, that minimizes operational expenses and that can be cost-effectively scaled to meet ever-increasing customer broadband demands. The cost of deploying and maintaining a network depends on

- Customer density and/or number of customers served
- Type of construction corridors
- Land and right-of-way issues
- Labor and fuel costs
- Network life expectancy
- Spectrum and regulatory costs
- Installation and maintenance costs.

These factors impact wireline and wireless deployments differently. Vantage Point Solutions calculated the cost to build either a wireless or wireline network in the exchange of Chamberlain, S.D. A map of the Chamberlain service area, which includes 1,650 locations covering about 200 square miles, is shown in Figure 4. Based on Vantage Point Solutions' experience in rural network design and

Figure 4: Chamberlain, S.D., is a typical rural service area of about 200 square miles.

deployment, Chamberlain is a typical rural area with rolling hills, a small community and sparsely populated outlying areas. From both a wireless and wireline perspective, Chamberlain is a moderately expensive area to serve.

COST TO BUILD A WIRELESS NETWORK

The primary costs of terrestrial wireless networks are the towers, tower electronics and backhaul. Rural towers have a much higher cost per customer than urban towers because there are fewer customers per tower and backhaul facilities often require significant construction.

New towers are most costly where land or rights-of-way are expensive. Land-use issues in general are more significant for wireless towers than for buried wireline facilities because of the visibility of wireless towers.

For the Chamberlain wireless design, VPS engineered a variety of scenarios in the 700 MHz band (2x5 MHz), 850 MHz band (2x10 MHz), PCS/AWS band (2x15 MHz) and BRS/EBS band (1x20 MHz). Each scenario developed a network with a high probability of delivering a 4 Mbps service while allowing users to burst to 10 Mbps. LTE was chosen as the wireless technology because it is the

	2x5 MHz Total Tower Sites: 29	2x10 MHz Total Tower Sites: 15	2x15 MHz Total Tower Sites: 10	1x20 MHz Total Tower Sites: 9
Radio Network Equipment	$4,181,000	$2,512,000	$1,918,000	$1,949,000
Core Network Equipment	$592,000	$342,000	$249,000	$229,000
Fiber Backhaul	$2,980,000	$2,636,000	$2,631,000	$2,423,000
Total Investment	**$7,753,000**	**$5,490,000**	**$4,798,000**	**$4,601,000**
Capacity Cost	**$470**	**$330**	**$290**	**$280**

Table 2: Wireless initial investment costs for Chamberlain, S.D. (BHOL=444 Kbps); costs were much higher for BHOL=888 Kbps

most advanced technology available today and can be used for all the chosen frequency bands. With the subscriber density of Chamberlain and the service rate of 10 Mbps, any wireless network would be capacity constrained versus being range limited; therefore, no cost reduction could be realized by utilizing sub-2 GHz bands, which can propagate over longer distances.

The analysis was based on the following assumptions:

- No spectrum costs were included. Spectrum prices vary widely from one market to another; thus, spectrum costs would be difficult to estimate for a specific geographic area. Excluding spectrum costs gives an economic advantage to the wireless network being examined here.
- All customers, both town and rural, would be served by the wireless broadband network as if no wireline network were available.
- For backhaul, fiber would be installed from each tower to the central office.
- Less than 6 percent of the estimated cost of the core network investment was attributed to the Chamberlain design. Although no other users were identified to share the core network, 94 percent of the core network costs were not attributed to the wireless carrier, giving it another economic advantage.
- Towers were located close to each customer to enable the use of lower-cost indoor residential LTE modems rather than more-expensive outdoor modems.
- Each tower's serving area was small enough so that lower-cost towers could be used. Most towers were only 60 feet high.
- A busy hour offered load (average demand for network capacity across all subscribers during the busiest hour) of 444 Kbps was assumed, based on a 4 Mbps service and the FCC's prediction of what would be required by 2015. As the FCC standard for CAF support is now 10 Mbps, we also analyzed a system with a BHOL of 888 Kbps.

The cost estimates and capacity cost (investment required to deliver 1 Mbps to each customer) are summarized in Table 2. Raising the busy hour offered load to 888 Kbps showed that significant additional investment is required as broadband demand increases.

COST TO BUILD A WIRELINE NETWORK

Three technologies are commonly used by wireline companies today: DSL, DOCSIS over coaxial cable and fiber to the premises.

Fiber has been acknowledged as the best technology to construct modern broadband networks or to upgrade existing networks because it is immune to electromagnetic interference, provides the most reliable services, minimizes operational expenses and is economically scalable to achieve higher broadband speeds. In addition, fiber optics has the ability to deliver greater bandwidth over a much larger distance and at a lower cost than other technologies.

In addition to the fiber cable, an FTTP network requires electronics at the customer premises and at the node. The cost of electronics per location serviced is relatively constant, but fiber cable investment is quite variable and usually represents the majority of the cost. Vantage Point Solutions' experience is that significant cost drivers for wireline deployments include

- Lower customer density – In rural areas, there are few customers to share the infrastructure costs, which results in a high cost per customer.
- Difficult construction corridors – Terrain difficulties include obstacles such as rocks, lava flows, lakes, rivers, forested areas and railroad crossings. The type and quantity of existing underground utilities also significantly influence construction costs, as extra effort is required to circumvent the utilities.
- Land and right-of-way Issues – Cable construction becomes more difficult and costly where land or ROW is expensive.
- Labor and fuel costs – Cable construction is labor-intensive and relies on the use and transportation of large equipment. Typically, 60 to 80 percent of the construction costs are labor related.

Table 3 shows the estimated FTTP initial investment to build an active Ethernet network capable of 1 Gbps, including the fiber construction, electronics, miscellaneous materials and overheads.

	Cost
Outside Plant	$6,900,000
Electronics	$1,560,000
Total Investment	**$8,460,000**
Capacity Cost	**$ 5**

Table 3: FTTP initial investment cost

WIRELINE NETWORK'S PERFORMANCE SURPASSES THAT OF THE WIRELESS NETWORK

Depending upon terrain, desired broadband speeds and other factors, the initial capital expenditure for a wireless broadband network may be less than the initial capital expenditure for an FTTP network. In this example, however, the initial cost of a wireless LTE network can be more or less than the wireline FTTP network depending upon the assumptions.

Importantly, the performance of the two networks is not comparable. The wireless network was designed to have a high probability of delivering 4 Mbps and allow customers to occasionally burst to 10 Mbps. As mentioned earlier, if all customers on the wireless network attempt to use the maximum capacity, each will be able to achieve a speed of less than 0.5Mbps (444 Kbps). Each customer on the FTTP network will receive 1 Gbps service no matter how many customers are using the network because it is not oversubscribed between the customer and the central office.

When comparing the capacity cost (the cost to deliver each Mbps to a customer), the FTTP network costs approximately $5 per Mbps compared with between $280 and $710 per Mbps for the wireless network. When comparing wireless and FTTP investments, it is important to consider the following:

- Spectrum costs and 94 percent of the core network costs were excluded from the wireless network cost estimate and would contribute significantly to the overall capital investment for wireless deployments.
- The majority of the FTTP investment is in cable facilities, whereas the majority of the wireless network investment is in electronics. The economic life of cable facilities is typically 30 years or longer, and electronics often last between 5 and 10 years. To appropriately compare the two networks from a financial standpoint, the different economic lives must be equalized, which will lessen any perceived cost savings for a wireless network.
- The FTTP network can be scaled to provide faster speeds and greater capacity much more economically than the wireless network. If users were to demand more than 1 Gbps service in the future, only the FTTP electronics would need to be replaced. Because the cost of electronics is proportionately lower compared with the initial deployment cost of fiber, the FTTP network can be upgraded cost-effectively.

Both scenarios assumed that no existing facilities were considered in the design. The cost of a wireless network could possibly be reduced by using existing structures, but the decrease in investment would likely be small, considering the number of towers required to meet the speed and capacity requirements.

Engineering analyses confirm that wireline technologies are capable of providing the best broadband services in terms of speed, latency, capacity and reliability. Wireline technologies are capable of speeds many times faster than the preeminent wireless technologies, and they are not plagued by the latency issues or the scarce spectrum resources that limit speed and capacity in wireless networks.

The FCC recognizes that fiber is the only last-mile technology capable of meeting long-term broadband needs. As FCC Chairman Wheeler said: "In the end, at this moment, only fiber gives the local cable company a competitive run for its money. Once fiber is in place, its beauty is that throughput increases are largely a matter of upgrading the electronics at both ends, something that costs much less than laying new connections."

Both wireless and wireline broadband services play important roles in many customers' lives, and neither one will ever displace the other. Today's customers expect an assortment of applications in a variety of locations. Mobile wireless broadband services are required to meet customers' mobile needs, and wireline broadband services are required to provide high-quality broadband for the rich multimedia experience customers expect in their homes and businesses.

Wireline and wireless services are complementary in the lives of their customers, and they are complementary in the sense that wireless service depends on the speed and quality of wireline connections. Wireless towers require high-capacity connections, typically using Ethernet delivered over a landline carrier's fiber network. ❖

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