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BROADBAND CONNECTITY ANALYSIS

Introba

REPORT FOR:

Washington State Utilities and Transportation Commission

Broadband Connectivity Technical Analysis

Executive Summary

The evolution of broadband technology has significantly transformed how people connect to the internet, but the services available continually escalate the need for higher performance and faster connections. The analysis on the following pages reviews the local drop to the end-user (the last mail) and the extension of the ISP backbone (the middle mile). The report examines capital costs (installation), contributing factors, and performance expectations.

Fiber optic cabling is the most appropriate technology for backbone expansion (the middle mile). The industry has embraced fiber to meet the growing capacity demand and the need to cost-effectively aggregate downstream users without reinvesting in additional backbone cables. The cable companies and the wireless carriers are moving to fiber to support their growth plans. Per-mile installation costs are roughly equal to other wired options (such as coax) but far outperform all other technologies.

The local loops to households and businesses (the last mile) have a more varied set of options and a less clear preferred technology. As described above, fiber will deliver the best throughput/capacity, but it can carry a high per-drop cost, especially for rural users not close to the right-of-way. Some current options for connection provide acceptable performance, including many that approach the 100 Mbps down and 20 Mbps FCC broadband definition. However, the options to reach the 150/150 symmetrical throughput goals, the local loop choices are currently limited to fiber to the home (FTTH) networks, HFC cable networks (especially those upgrading to DOCIS 4.0), and hybrid networks that leverage modern WiFi technology for the local drops and fiber for the backbone.

A summary table at the end of the report provides a quick comparison.

Connectivity Analysis Introduction

Well-populated urban areas usually include enough paying customers to provide a rate of return (ROI) for the investment in upgraded telecommunications infrastructure. Rural areas typically suffer from a lack of adequate telecommunications infrastructure. The distances between households and the lack of density (paying customers) create a financial challenge for providers in obtaining a profitable ROI. As a result, rural residents and businesses often find themselves with inadequate internet coverage or dependent on slow, unreliable connections.

Last Mile Internet Connectivity

The last mile, sometimes called the local loop, refers to the final leg of the telecommunications networks that deliver services to end customers. For the purposes of this report, the local loop is referring to the service link from the right-of-way to the household or business. Since it is the single link to the property, often the local loop is serving a single paying customer. The different types of local loop can include the copper wire lines connecting landline telephones to the local telephone exchange, coaxial cable service drops carrying cable television signals to subscribers' homes, and cell towers linking a cell phone to the cellular network. The word "mile" is used metaphorically; the length of the local loop is usually less than a mile.

Not all last-mile transport mediums are created equal. For many urban users, there are several options for physical transport medium, and the length of that drop tends to be short. For many rural users, there are fewer options and often higher costs, especially when the local loop is lengthy. It is essential to recognize that the last mile capability is critical to overall performance.

The last mile is typically the speed bottleneck in telecommunication networks; its bandwidth effectively limits how much data can be delivered to the customer. Because local loops are the most numerous elements, they are an expensive part of a deployment plan and the most difficult to upgrade to new technology.

Middle Mile Connectivity

Middle-mile connectivity covers the telecommunications segment between the last mile and the internet backbone. For many Internet Service Providers (ISPs), the middle mile is their "core" network. Due to construction costs, many ISPs leverage other (existing) physical networks by contracting for access or swapping resources with other ISPs. However, when obtained from an incumbent operator, middle-mile access is a major expense for non-incumbent broadband ISPs. The alternative, building out their own backbone networks, is capital-intensive.

For this reason, many proposals for government broadband stimulus initiatives are directed at building out the middle mile, including projects such as the National Telecommunications and Information Administration (NTIA) grants as part of the Enabling Middle Mile Broadband Infrastructure Program. Open access concepts like duct sharing, utility pole sharing, and fiber unbundling can ease the middle mile cost problem. Washington State DOT and many local utilities have installed fiber in the right-of-way to provide (wholesale) access to ISPs and carriers that complete the network services connections and own the relationship with the end users.

From a total network performance perspective, the middle mile must have enough capacity to handle the aggregated bandwidth from the downstream connections. The technology that provides the most total bandwidth and is cost-effective for this role is fiber optic based. Fiber optic transmission provides low latency and resistance to interference from weather conditions and electromagnetic energy sources. Although there are different transport technologies (both passive and active networks), fiber optic cabling is the most appropriate for backhaul connections, even when the last mile distribution is wireless or coax links.

Cost Elements

Wired Network Costs

In middle-mile deployments, it is clear that fiber is the best option for a wired backbone (over copper or coax). The first reason is installation costs: the primary construction cost to install either aerial or underground telecom infrastructure is the same regardless of the medium. The equipment required (bucket trucks, backhoes, etc.) and the installation labor are nearly identical. The labor cost per foot exceeds the material cost for a fiber cable, copper cable, or coaxial cable per foot. In January 2024, the Fiber Broadband Association (FBA) announced the results of its first Fiber Deployment Cost Study, providing the industry's benchmark for costs in the US. The survey found that, on average, labor contributed 73% of underground build costs and 67% of aerial costs. Even the cost of materials is in the same range for each cable. Fiber maintenance costs are also typically lower with faster restoration when needing servicing. According to a detailed 2020 survey by the Fiber Broadband Association, operational support costs for fiber run about 40% less than coax and HFC networks and over 60% less than copper cables. Copper-based cables have also become a target of thieves looking to make money on recycling.

The other main reason fiber is the preferred medium for new installations is also clear: fiber optic capacity and future capabilities far exceed copper's long-term return on investment possibilities. Incumbent carriers are abandoning the legacy multi-pair copper cables (and not installing any new ones), and cable companies are upgrading their backbone from coax to fiber.

Wired networks can be installed on aerial utility poles or as underground infrastructures. The cost per foot of aerial deployment is less than half of underground, with reported costs ranging from about $4 to $9 per foot ($20,000 to $45,000 per mile), as compared to $10 to $23 per foot ($50,000 to $120,000 per mile) for underground deployment. As stated before, these installation costs don't vary much when comparing copper, coax, or fiber cables. The 2023 Fiber Deployment Cost Survey determined the <u>median</u> cost of deploying fiber underground is about twice that of deploying fiber aerially. The same ratio (aerial to underground construction costs) applies to copper cables and coax cables as well.

Choosing between aerial or underground (for any physical cable) was driven by factors including access to poles, risk of adverse weather events, and deployment costs. Underground deployment was viewed as more resilient and better protected against adverse weather, such as hurricanes, tornados, high winds, and ice storms.

Using aerial is dependent upon physical access to poles, with economic factors potentially driving projects towards underground. Make-ready costs can vary significantly, often adding $5 to $6 per foot to unit costs (which can double the total per-mile costs) or requiring the installation firm to install dedicated poles. More recently, the shortage of properly trained and equipped aerial crews has created delays and higher costs due to reduced competition.

Underground construction methods will also impact costs. Per the above survey, trenching had the lowest reported median cost at $12 per foot ($60,000 per mile), and plowing had the highest median cost at $17 per foot ($90,000 per mile). Directional boring fell in the middle at a median of over $15 per foot.

Population density greatly impacts the cost per foot of aerial and underground builds, with median costs increasing with density. Extremely rural areas represent the lowest median costs, with $5 per foot for aerial ($26,000 per mile) and $12.50 per foot for underground ($66,000 per mile). Urban areas had the highest median costs at $6.54 per foot for aerial and a whopping $23.25 per foot for underground.

Terrain plays a significant role in costs, with underground costs especially affected. The denser and harder the terrain is, the more costly it becomes to dig under the surface, regardless of the method involved. Underground deployments have a median cost of $10 per square foot in soft earth and double that in rocky terrain at $20 per square foot. Rocky terrain is more expensive, requiring more cutting and drilling, with slower progress.

The 2023 study also considered deployment costs by region, and the West aerial range ran from $6 to $12.50 per foot ($31,000 to $66,000 per mile) and $15 to $29 per foot ($79,000 to $150,000) for underground deployments, which is much higher than other parts of the country.

As mentioned above, this installation (construction) cost ranges apply to fiber, copper, or coax cables. If there are many users planned for the cable (requiring a higher pair-count copper cable), then copper cables become even more expensive and still have limited capacity. Coax networks also have throughput restrictions, especially with the upstream bandwidth available. Thus, on a bandwidth-per-foot calculation approach, it is easy to see why fiber is the most cost-effective and preferred physical medium for backbone and middle-mile networks.

Wireless Network Costs

Using wireless options for the middle mile is not as cost-effective. The first reason is that the capacity of fiber networks far exceeds the capacity of wireless technology, especially when aggregating the bandwidth from multiple end-users. Another reason is the expected life span – wireless technology development is on about a five-year cycle, and each new version typically requires new radios to gain performance advantages. Even with point-to-point wireless options such as microwave or mesh (multi-radio backhaul) networks, the capacities cannot come close to the fiber and even coax-based backbone networks. Many of the commonly used RF frequencies (cush as the WiFi bands) are unlicensed and subject to over-saturation and interference. Dedicated and licensed radio frequencies may protect against outside interference, but RF licenses are in high-demand, expensive, and not always available due to existing license holders in the area.

Local Loop Costs

The last-mile access line is the largest part of the per-home average telecom/ internet network investment. Some utility experts use a 1:3:10 investment ratio, where the middle-mile will cost three times the backbone (on a per-user basis) but the local loop costs will be ten times the backbone costs. The useful life of a fiber access line is 30 to 40 years, but this multiplier of the total number of homes (drops) makes it a sizable overall investment—much more significant than investments in other parts of the network.

Middle-mile and core networks are generally shared between many customers, so capacity can be reallocated. These shared networks can be incrementally extended and increased in capacity as demand grows.

However, in contrast, there is only one potential customer for a last-mile access line: the occupant of the home. Most of the cash outlay goes to laying the access line, and it’s all sunk costs. The investment can only be recovered as long as there is a paying subscriber. Because the local loop is not removed if the customer quits paying for services, the ROI stops until there is a new or returning account. It is impossible to reallocate that access line investment to another potential customer, so each local drop either pays for itself or not.

The above is one reason why hybrid wired-wireless networks have some appeal. The wireless drop (local loop) electronics can be reallocated when the service is discontinued, and there is minimal danger of on-site reconfiguration or construction impacting the service loop.

A critical factor in a network provider obtaining a reasonable ROI is the penetration rate (or take rate); even a twenty percent increase in households ordering service can change the feasibility of a build-out. One factor that has limited the ability to connect to some households is the distance from the right-of-way, and many carriers ask the homeowners to pay for the cost of installing the wired local loop.

Comparison of Connectivity Options

The last mile is the final part of the telecommunications network chain – the part that physically reaches the customer's property. This critical segment bridges the gap between local internet service providers (ISP) and residential users. Several technologies serve this purpose, each offering unique advantages and limitations.

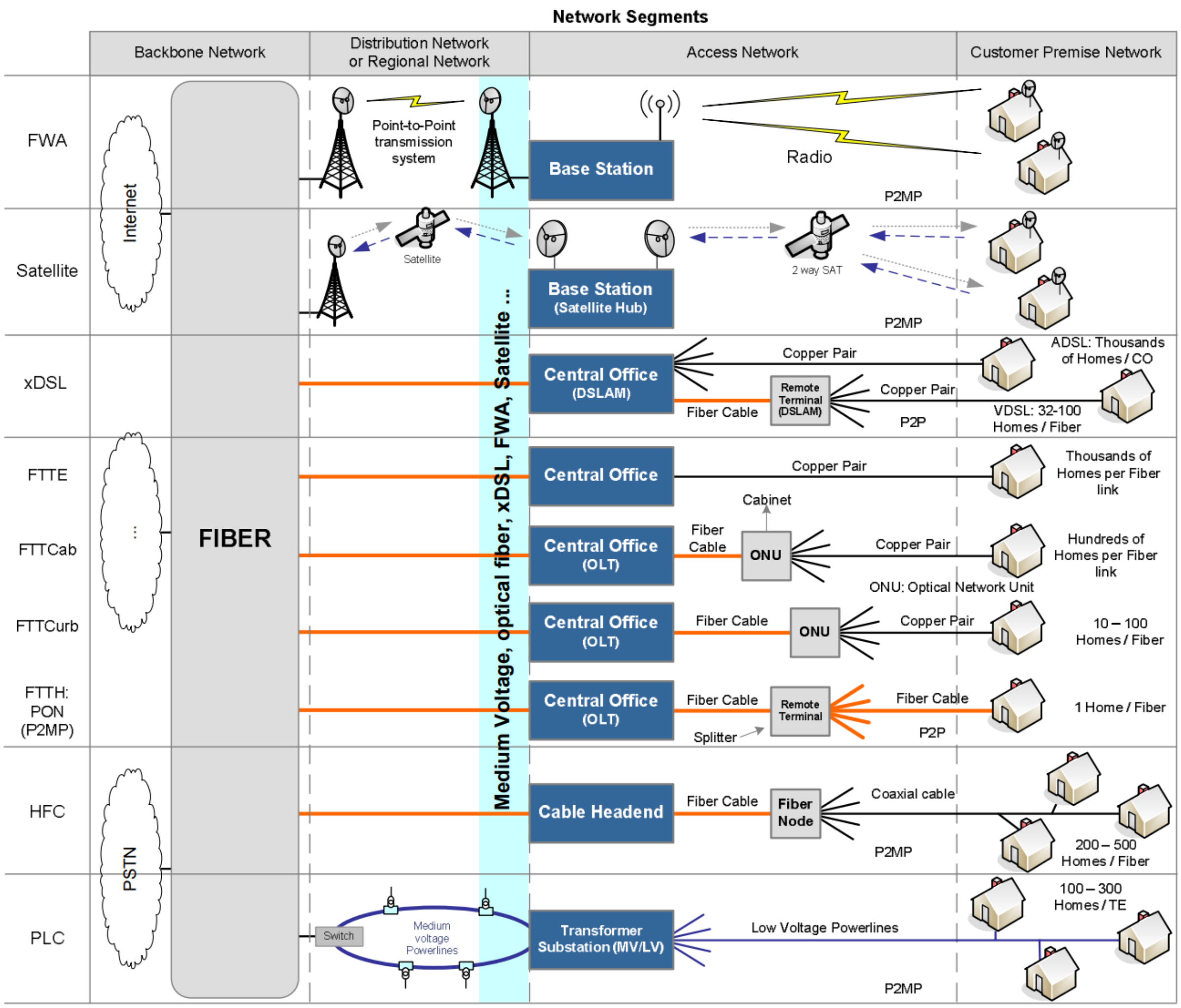

Figure 1: Broadband Access Network Technologies

Below is a comparison of the primary last-mile options for broadband connections: Digital Subscriber Line (DSL), Fiber to the Home (FTTH), Cable, Fixed Wireless (including WiFi), and Satellite.

Digital Subscriber Line (DSL)

Overview

DSL technology leverages existing telephone lines to deliver internet connectivity. Thanks to the extensive infrastructure of legacy telephone lines, it is one of the most widely available broadband technologies. A few carriers have combined fiber backbone with DSL last mile drops to improve end-user throughput, but this is inconsistently available, less reliable, and poorly supported. Due to speed and distance limitations and better alternatives, DSL market share has been dropping, with current estimates under 10% of all broadband access lines.

Advantages

- Wide Availability: DSL is accessible in many areas where telephone lines exist.
- Cost-Effective: Generally, DSL is less expensive than other internet options.
- Simultaneous Use: Allows the use of internet and standard public switched telephone network (PSTN) services at the same time.

Limitations

- DSL performance degrades with distance from the central office.
- Speed Limitations: Most DSL services cannot meet acceptable broadband bandwidth definitions, with much lower throughput than fiber and cable. However, some providers claim to reach acceptable throughput when using fiber backhaul.
- Asymmetrical: Most DSL service provides relatively low upload speeds.
- Older Technology: As an older technology based on telephone company copper cables, DSL will not meet the increasing demand for higher bandwidth.

Costs / Value

The legacy carriers that installed copper cables to support basic telephone services have leveraged the existing infrastructure to provide data networking services, including DSL. Thus, the cost of building out DSL services was minimized, but the maintenance costs are more significant due to the cost of maintaining the copper circuits and the required electronics. As carriers want to abandon the copper backbone networks, the future of copper and DSL technologies is limited.

Fiber to the Home (FTTH)

Overview

FTTH technology delivers internet directly to homes using fiber-optic cables. A network device typically provides standard Ethernet ports for user connections. Variations include fiber run to a node in the neighborhood (FTTx), with ethernet copper installed from the node to the household.

Advantages

- High Speed: FTTH provides the fastest internet speeds, often exceeding 1 Gbps.
- Low Attenuation: Light signals can be transmitted over long distances without degradation.
- Reliability: Light signals are immune to electromagnetic interference, offering a cleaner and more reliable method of data transmission.
- Low Latency: Fiber electronics /networks typically have excellent packet delivery (low loss and low latency).
- Symmetrical: Although it is not always sold as a symmetrical service, fiber optic easily supports fast upload speeds.

- Future-Proof: Capable of meeting increasing bandwidth demands due to its high capacity; upgrading electronics can improve performance without replacing the backbone.
- Bundling Options: Often available in bundles with cable TV and phone services.
- Reduced Maintenance: Fiber maintenance is less expensive than copper/cable costs.

Limitations

- High Cost: Installation costs are significantly higher than many wireless local loop options.
- Limited Availability: FTTH is primarily available in urban and suburban areas, with limited reach in rural regions.

Costs / Value

Fiber network installation costs are high (as discussed above), but the long lifespan and expandable throughput make fiber a cost-effective choice, especially when serving localized concentrations of users. A local loop to homes can be significant, especially if the dwelling is far from the right-of-way backbone cable. However, there is little difference in the cost among wired options between installing a new fiber drop cable versus installing a new coax or copper drop cable. Even with high installation costs, the long lifespan and ability to meet future demands make it a high-value option.

Cable (Coax)

Overview

Cable internet uses the same coaxial cables that deliver cable television to provide internet services. Most cable providers are upgrading backbone segments to fiber, and many have implemented fiber-to-the-curb designs, using coax cable to enter sites (see next section).

Advantages

- High Speed: Cable internet can offer high speeds comparable to FTTH in many instances.
- Availability: Widely available in urban and suburban areas where cable TV services exist.
- Advancing Technology: The DOCSIS (data over cable service interface specification) international standards are improving – the latest (DOCSIS 4.0) provides download speeds up to 10 Gbps and upload speeds up to 6 Gbps.
- Bundling Options: Often available in bundles with cable TV, phone services, and security monitoring, sometimes at a lower total cost.

Limitations

- Rural Availability: Because cable companies (unlike telephone companies) never had a mandate to serve all users, many areas do not have a cable service option.
- Shared Bandwidth: Speeds can fluctuate because bandwidth is shared among users in the same area; this is minimized when the cable backbone is upgraded to fiber.
- Asymmetrical: With most cable networks, the download speed is much faster than the upload speed, making the plan asymmetrical. Even with DOCSIS 3.1, upload speeds are one-tenth of download speeds. A fiber backbone and DOCSIS 4.0 will change this.

- Network Congestion: Performance may degrade during peak usage times; this is minimized when fiber-to-the-curb or fiber-to-the-neighborhood has been implemented.

Costs / Value

Coax-based cable network installation costs are high (equal to fiber for a new drop) and only make economic sense when the core network is already in place, and the new service is an extension. As before, a new local loop to homes can be significant, especially if the dwelling is far from the right-of-way backbone cable. Some cable companies may find construction and maintenance cost advantages to staying with an all-coax network for expansion and new customers, rather then converting to the hybrid networks described below.

Hybrid Fiber Coax (HFC)

Overview

HFC providers are typically cable companies that have upgraded their backbone from coax to fiber while still using the installed local loop coax cable to provide service to a home or business. Few new installations will use this model since installing a coax drop to a residence has the same costs as using a fiber drop, and the conversion (from fiber to coax) electronics adds costs and additional maintenance requirements. Thus, an HFC is somewhat of a subset of standard coax network, but a dedicated coax drop to a fiber backbone has more capacity than an all-coax network where the backbone becomes the limiting factor due to aggregation.

Advantages

- High Speed: HFC internet can offer high speeds comparable to FTTH.
- Availability: Widely available in urban and suburban areas where cable TV services exist.
- Bundling Options: Often available in bundles with cable TV, phone services, and security monitoring, sometimes at a lower cost.

Limitations

- Rural Availability: Because cable companies (unlike telephone companies) never had a mandate to serve all users, many areas do not have an HFC service option.
- Added Complexity: Cable companies running new services to a previously unserved area are less likely to install HFC because of the added complexity. However, a cable company may prefer an HFC approach if it matches the rest of its architecture and is compatible with a common set of termination electronics.

Costs / Value

HFC networks can be cost-effective when the local loop exists or is a short drop from the robust fiber-based backbone. As before, installation costs are high (equal to fiber for a new drop) and can be a good choice when it matches the deployment architecture of the cable provider. The lifespan of an HFC network will be better than that of a total coax configuration.

Fixed Wireless Access (FWA)

Overview

Fixed wireless internet delivers broadband using radio signals between towers and a receiver installed at the customer's home. Some of the more common options are from the cell phone providers, leveraging frequencies they control and existing infrastructure. Other once-promising technologies such as WiMAX ((Worldwide Interoperability for Microwave Access) have been bypassed by parallel technology developments, including 5th Generation cellular, and have lost significant market share over the past 10-15 years. Because the FWA local loop (last mile) can cover longer distances, it overlaps with the middle-mile distribution of other technologies.

Advantages

- Flexibility: Can be deployed in areas where traditional wired connections are impractical.
- Quick Installation: It is generally faster to set up since it doesn't require laying cables.
- Purposeful Design: FWA often uses frequencies and technology designed for cellular networks but modified for non-mobile devices, making it more efficient and cost-effective.
- Scalability: FWA can scale to meet localized demand and be upgraded with minimal disruption; it also benefits from continued radio transmission performance improvements.
- Cost-Effective: Lower infrastructure costs make it a more affordable option in some areas.

Limitations

- Speed Limitations: Lower speeds compared to fiber and cable; current <u>average</u> download speeds are about 120 Mbps, and upload speeds are under 20 Mbps. However, 5G versions of FWA are improving throughput potential, and some vendors are claiming up to 1 Gbps is possible (although with limited simultaneous subscribers).
- Receiving Antenna Requirement: Homes often need additional equipment to receive and extend the signal to internal network equipment. Higher (millimeter) wavelength radio frequencies allocated cannot penetrate buildings or other obstructions; for these higher bandwidth capabilities, the receiving antenna must be outdoors.
- Divergent Signals: Broadcast RF signals are not guided to a specific point; those receiving signals compete for bandwidth access.
- Signal (line-of-sight) Issues: Performance can be affected by physical obstructions between the tower and the receiver. Also, RF waves' reflection, refraction, and diffraction can impact the transmission characteristics. These issues limit the workable transmission distance.
- Weather Dependency: Signal quality may degrade during adverse weather conditions, although it is more dependable than satellite signals.

Costs / Value

FWA network installation costs are relatively low for the local loop, although the expected technology lifespan is shorter than that of fiber optic cable and will require more frequent reinvestment. This option may especially be helpful when the dwelling is not close to any internet backbone cables. Its continued value will be dependent upon further improvements in throughput.

WiFi

Overview

Standard WiFi technology allows last-mile connectivity within a limited range by establishing wireless local area networks (WLANs). There are WiFi transmission antennas that have a more extensive reach (distance) than standard Wireless Access Points (WAPs), although signal backhaul remains an issue. Some vendors use a fiber backbone to reach the outdoor WAPs, while others use wireless mesh networking to connect units. Both sixth generation (802.11ax) and seventh generation WiFi (802.11be, standard to be finalized this year) WAPs can provide well over the 150 Mbps goal, but it requires using 40 MHz OFDMA (Orthogonal Frequency Division Multiple Access) channels. This design will limit the number of simultaneous users to 18 at the defined speeds, which will likely be adequate in most rural installations.

Advantages

- Hybrid Networking: Leverages wireless for the last leg but can connect to various middle-mile technologies, including fiber backbones, to create robust networks.
- Low Cost per User Site: Avoids installing physical cables from the right-of-way into the premises, saving money. Some WiFi radio/antenna units are designed for up to 5,000 feet of directional coverage, although standard WiFi signals have a shorter reach.
- Faster Installation: Wireless local loops can be turned up (deployed) quickly.
- Familiarity: WiFi access is common enough to be "understood" by many installers, technicians, and end users, which can simplify setup and troubleshooting.
- Scalable/Capacity: Modern WiFi is designed for greater user density and can adjust signal allocation in real-time, which makes it more flexible and scalable.

Limitations

- Shared Bandwidth: If there are many end devices per WAP, performance can be affected due to the maximum capacity of the wireless spectrum. Wireless mesh (backhaul) networking can also cause additional throughput contention.
- Security: WiFi signals may be subject to interception and related security risks.
- Weather Impacts: Signal quality can be affected by extreme weather conditions such as heavy rain, snow, or storms.
- Rapidly Changing Technology: WiFi improvements require reinvestment in new electronics, but there is also a need to maintain backward compatibility until old equipment is replaced.

Costs / Value

WiFi, as part of a hybrid approach (with a fiber backhaul), can be very cost-effective, especially when looking to offset the local drop cost to a site. Current technologies already support excellent throughput levels. However, the equipment lifespan is shorter, and reinvestment will be required as new technology (and potentially new frequencies) are implemented. Range, which is less than other FWA electronics, creates a need for more transmission antennas.

Satellite

Overview

Satellite internet uses communication satellites to provide broadband services to users, making it accessible in remote and rural areas. Different satellite constellations provide a varied level of performance; low earth orbit satellites have higher speeds and lower latency.

Advantages

- Wide Coverage: Can reach areas where other types of broadband are unavailable, including remote and rural locations.
- Independent Infrastructure: Does not rely on terrestrial infrastructure, reducing vulnerability to local disruptions.
- Faster Installation: Avoiding the need for infrastructure allows for quicker deployment.

Limitations

- Latency: Higher latency is due to the long-distance signals that must travel, affecting real-time applications like gaming and video calls. Geo-centric satellites have about 270 milli-second round-trip delays, which is unacceptable for real-time/two-way communications.
- Variable latency: The signal distance to low-earth orbit satellites varies as the satellites move (Doppler shift effect), with variance (jitter) reaching as much as 12ms (total latency for the best satellite network is typically around 40ms).
- Data Caps: Often comes with data limits, which can restrict usage.
- Weather Dependency: Signal quality can be affected by weather conditions such as heavy rain or storms.
- High Cost for Users: Generally, more expensive than other broadband options, both in terms of equipment and service fees.
- Current Speed Limitations: Although the best satellite network claims download speeds between 50 and 220 Mbps, upload speeds are typically between 5 and 20 Mbps.

Costs / Value

Satellite service has a “low” cost for the local drop, and the receiving equipment is typically a cost borne by the end user. The satellite constellations comprising the backbone are very expensive, and it is unlikely any new satellite providers (beyond the current three) will surface soon. The value is good for isolated and remote sites that are too costly for standard terrestrial-based network providers. However, speed and latency issues will prevent Satellites from meeting the advanced broadband performance targets, and it is not appropriate for State-sponsored funding programs.

Conclusion

The best last-mile option for broadband connectivity depends on several factors, including location, budget, and specific usage needs. FTTH and cable offer excellent speed and reliability for urban and suburban residents but at varying cost points. Unless the coax cable is already in place, fiber costs are similar enough to warrant being favored over a new coax cable drop. Rural areas might benefit more from wireless options despite certain limitations in speed and latency.

Middle-mile and backhaul services are best served by fiber optic cabling. Fiber offers unmatched potential for very high bandwidth, low latency, and immunity to electromagnetic interference. It will have the longest usable lifespan and can be integrated with various local loop connections for distribution to end users. However, the per-subscriber costs for rural fiber backbone remain high, which is why public funding is a common aid to help with the build-out.

While fiber-optic broadband is the industry favorite for robust and reliable connectivity, it is not a panacea. A hybrid approach to last-mile connectivity to achieve 150/150 Mbps connectivity should consider viable wireless local loop options to connect unserved and underserved households cost-effectively and in a timely manner.

Local Loop Connectivity Options Summary Comparison

	Download Speed	Upload Speed	Local Loop Latency	Lifespan	Cost to Install (Construction)	Potential ROI for New
Copper (DSL)	1 – 100 Mbps	1 – 20 Mbps	15 – 40 ms	10 to 15 years	$0 from ILEC; NA from others	Very Low
Fiber	25 Mbps – 10G	25 Mbps – 10G	10 – 12 ms	30 – 40+ years	$600 to $25K (distance impact)	Moderate
FWA	50 – 250 Mbps	10 – 25 Mbps	10 – 15 ms	4 to 6 years	$400 to $600 per subscriber	Moderate
WiFi (6E) WiFi (7)	6 Mbps – 1G 10 Mbps – 30G	6 Mbps – 1G 10 Mbps – 30G	5 – 10 ms 5 – 10 ms	3 to 5 years 4 to 6 years	$200 to $500 per subscriber	Good
Cable (Coax)	25 – 300 Mbps	10 – 50 Mbps	12 – 30 ms	8 to 12 years	$500 to $20K (distance impact)	Moderate, but dropping
Hybrid Fiber Coax (HFC)	100 Mbps – 1G	25 Mbps – 1G	12 – 30 ms	10 to 20 years	$500 to $20K (distance impact)	Moderate
Satellite	5 – 220 Mbps	3 – 30 Mbps	30 – 300 ms	5 to 10 years	$600 - $2,500 per subscriber	Low

Middle-mile Options Summary Comparison

	Max Bandwidth/User	Upload Limits?	Lifespan	Cost to Install (Construction)	Repair Costs Yearly Budget*	ROI for New
Copper (DSL)	100 Mbps (usually less)	Yes, asymmetrical	10 to 15 years (but dropping)	$30K to $120K per mile	$150 to $175 per home passed	Very Low
Fiber	Nearly unlimited	No; symmetrical	20 – 30+ years	$30K to $120K per mile	$50 to $60 per home passed	High
Cable (Coax)	1 Gbps now; 10 Gbps future	Asymmetrical if DOCSIS <4.0	8 to 12 years	$25K to $100K per mile	$105 to $115 per home passed	Low
FWA Hybrid	1 Gbps (usually less)	Yes, normally asymmetrical	4 to 6 years	$800 to $1100 per household	$20 to $80 per subscriber	Moderate
Satellite	220 Mbps now; 1 Gbps (future)	Yes, asymmetrical	5 to 10 years	Over $1M per satellite	Very High; usable info N/A	Low

** Does not include depreciation or replacement costs*

About Introba

Introba, Inc., was formed in late 2022 as a rebranding of two sister companies, Integral, Inc. and Ross & Baruzzini. Introba is a global consulting engineering firm with over 1,000 employees with 52 licensed professional engineers and 15 Registered Communications Distribution Designers. This report's primary author is J.R. Simmons, Principal, Director Technology. Mr. Simmons has been a consultant for over 40 years and completed many telecommunications infrastructure projects and works closely with Introba's radio frequency engineers. He has also served as an expert witness for lawsuits involving outside plant construction disputes.

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