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BROADBAND 101

Fall 2022

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Broadband or High-Speed Internet ?

Broadband or High-Speed Internet?

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Broadband Definition

Broadband in telecommunication means a **wide bandwidth** which can transport multiple signals over a "**broad" range of frequencies** and support **different internet traffic types**, allowing **multiple data streams to be sent at once**.

High-Speed Internet Definition

High-speed Internet is a generic term used for Internet service that is **faster than the average**. Traditionally, the way to determine if a connection is high-speed is to test its ability to connect multiple devices simultaneously to allow streaming and access to modern applications.

Which Term to Use ?

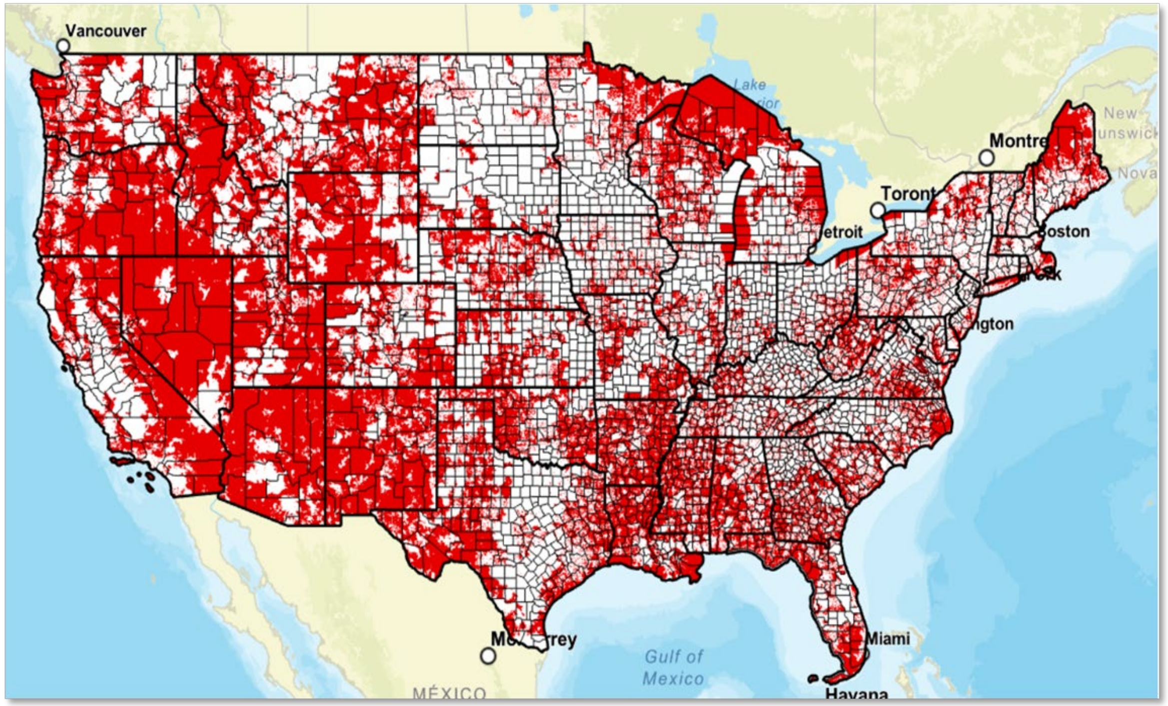
In essence, **the terms "Broadband" and "High-Speed Internet" are mostly interchangeable** when the internet speeds are at the **FCC standards, or higher** (i.e., a minimum of **25Mbps** for download & **3Mbps** for upload).

For purposes of this presentation, when talking infrastructure or technology, we will use the term Broadband and when talking about the service provided, we will use the term High-Speed Internet.

Overview of High Speed Internet in the USA

Millions of Americans Don't Have Reliable High-Speed Internet

- **17 million Americans do not have** High-Speed Internet @ 25/3 Mbps.
- **20.9% of Tribal lands and 17.2% of rural lands** do not have 25/3 Mbps High-Speed Internet.
- While 95.6% of household have access to 25/3 Mbps High-Speed Internet, **only 68.9% of households subscribe** to service at that level or above.

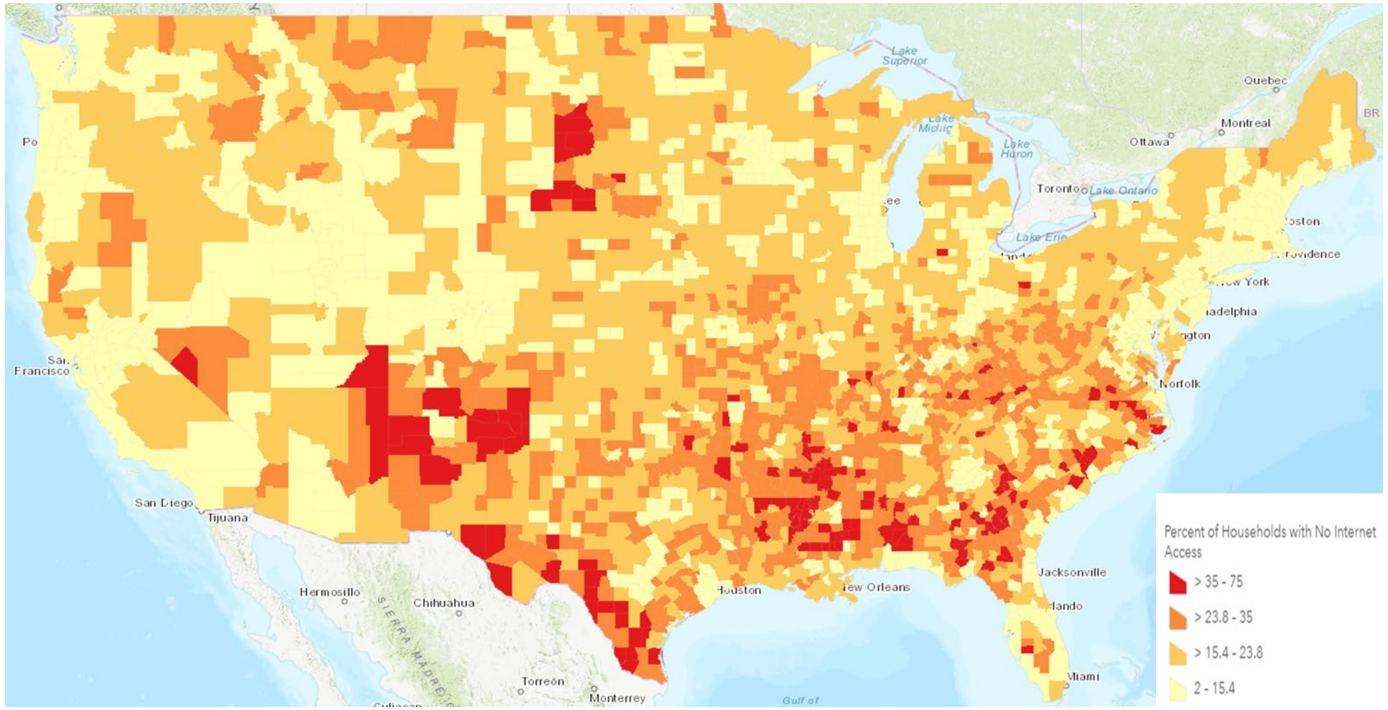


Red areas indicate where wireline High Speed Internet service is unavailable at the basic FCC benchmark speed of 25/3 Mbps - based on FCC Form 477 carrier-reported data.

Visualization: NTIA National Broadband Availability Map (NBAM)
Source: FCC 2021 Broadband Deployment Report, based on ISP-reported Form 477 data

High-Speed Internet Adoption is Uneven Across Communities

- **65 million Americans** do not use the Internet at all.
- **10 million Internet users** rely solely on a mobile data plan.
- **5 Million households** not online identified **cost as their main reason** for not using the Internet.
- Under-connected Americans are disproportionally likely to be low-income, non-white, rural, Tribal, older, and differently-abled.

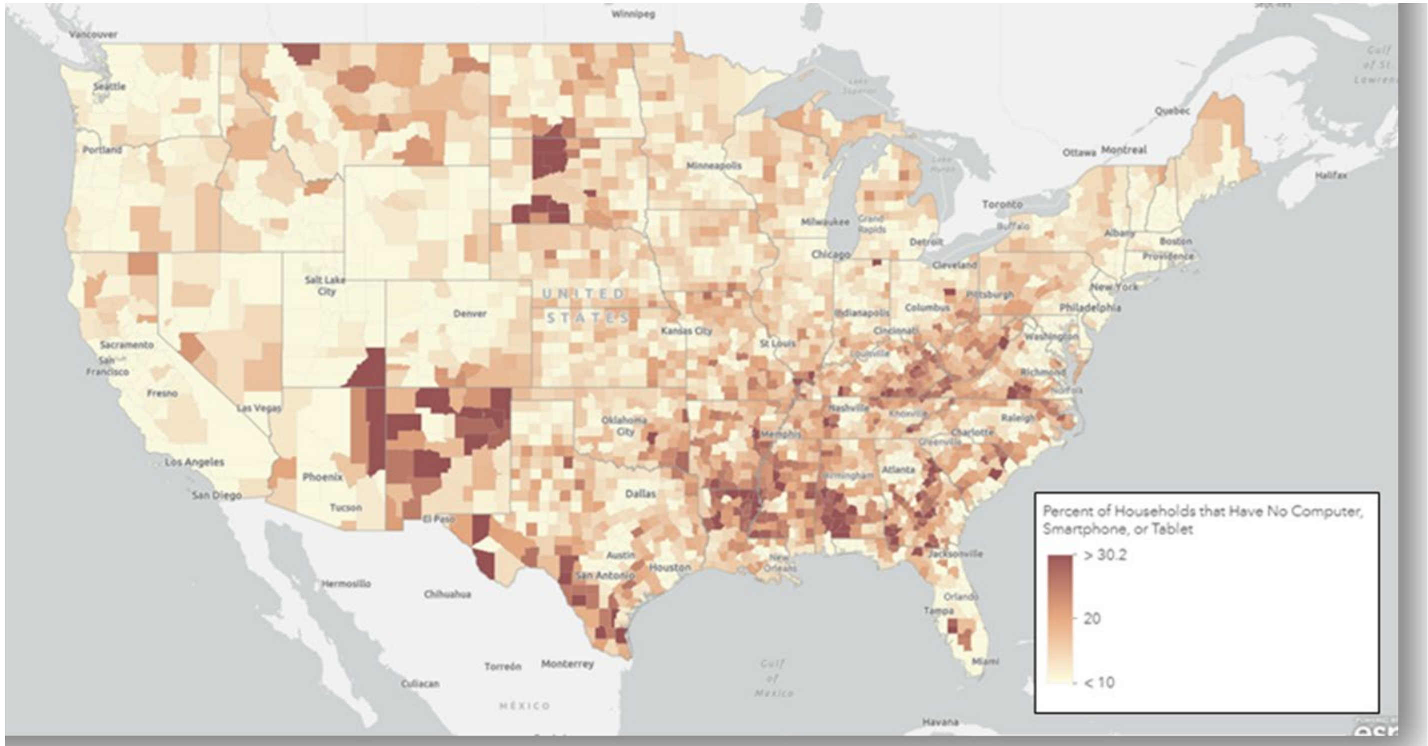


Red areas indicate places where more than 35% of the households have no Internet at all based on ACS subscription data.

Source one: NTIA Internet Use Survey, based on consumer 2019 surveys; American Community Survey Device Ownership data 2015-2019
Visualization: NTIA National Broadband Availability Map (NBAM)

It’s Time to Invest in the American Workforce

- **77% of all jobs** require at least some technology skills.
- **48% of hiring managers** say that candidates lack the skills needed to fill open jobs.
- **29% of students without basic digital skills** say they won’t consider post-secondary studies.
- **More than 12 millions households** lack access to a computer, tablet or smartphone.



Residents without devices have fewer opportunities to hone their digital skills, access educational opportunities, and advance in the workforce.

Visualization: NTIA National Broadband Availability Map (NBAM)
Source: American Community Survey Device Ownership data 2015-2019

Why High-Speed Internet Matters

Government Services

High-Speed Internet helps government agencies improve quality, lower costs and increase transparency by improving internal operations and making it easier for residents to interact with them online.

Telework

High-Speed Internet allows teleworkers opportunities to more readily live and work in locations of their own choosing, without having to be within commuting distance of a corporate center or another base location.

Education

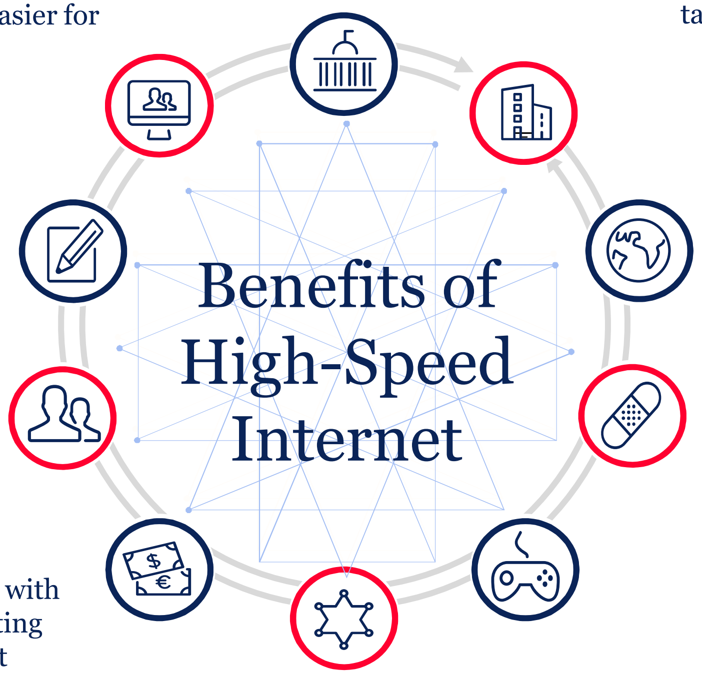
High-Speed Internet networks enhance educational experiences by providing students and teachers with access to an array of resources and the opportunity for distance learning.

Accessibility

High-Speed Internet is an important tool to address the needs of people with disabilities. Through various broadband-based applications and supporting technologies, people with disabilities have access to a new array of smart devices improving quality of life.

Economic Development

High-Speed Internet enables local communities, regions and nations to develop, attract, retain and expand job-creating businesses and institutions.



Urban Revitalization

Fully wired communities can provide residents with opportunities to take career and skill development classes, allow for more effective public safety and contribute to greater economic growth.

Environmental Sustainability

High-Speed Internet enables buildings to communicate with utilities and the energy market. Smart buildings and smart grids, hold great promise for greater efficiencies in energy consumption.

Healthcare

High-Speed Internet makes remote access to clinical services possible and cost-effective. It also allows physicians to monitor their patients through innovative home health devices.

Entertainment

High-Speed Internet is essential to enjoy 21st-century entertainment. Streaming video, online gaming and connecting with friends and relatives via social media are only possible because of broadband.

Public Safety

Wireless broadband, is becoming indispensable to the interoperability of police, fire, health and other government entities in both day-to-day and crisis situations.

NTIA
Bipartisan Infrastructure Law (BIL)
Broadband Funding Programs

NTIA BIL Broadband Funding Programs

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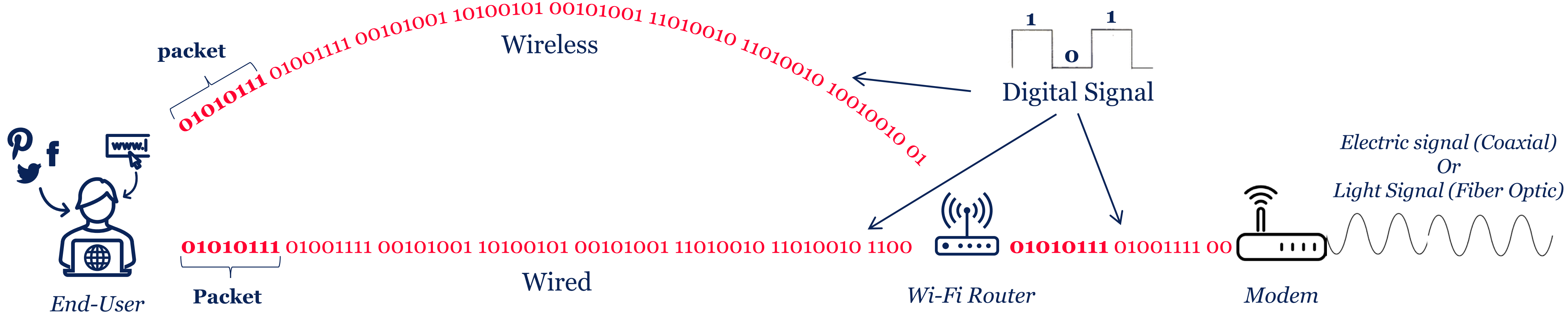
BROADBAND EQUITY, ACCESS, AND DEPLOYMENT	DIGITAL EQUITY	TRIBAL BROADBAND CONNECTIVITY PROGRAM	MIDDLE MILE
$42.45B	**$2.75B**	**+$2.00B**	**$1.00B**
Broadband Equity, Access & Deployment Program	**Digital Equity Act**	**Enabling Tribal Broadband Infrastructure**	**Enabling Middle Mile Broadband Infrastructure**
A program to get all Americans online by funding partnerships between states or territories, communities, and stakeholders to build infrastructure where we need it and increase adoption of high-speed Internet.	Three programs that provide funding to promote digital inclusion and advance equity for all. They aim to ensure that all communities can access and use affordable, reliable high-speed Internet to meet their needs and improve their lives.	A program for tribal governments to bring high-speed Internet to tribal lands. It also supports telehealth, distance learning, affordability, and digital inclusion initiatives.	A program to expand middle mile infrastructure, to reduce the cost of connecting unserved and underserved areas.

The Life of An Internet Packet

How does the Internet work ?

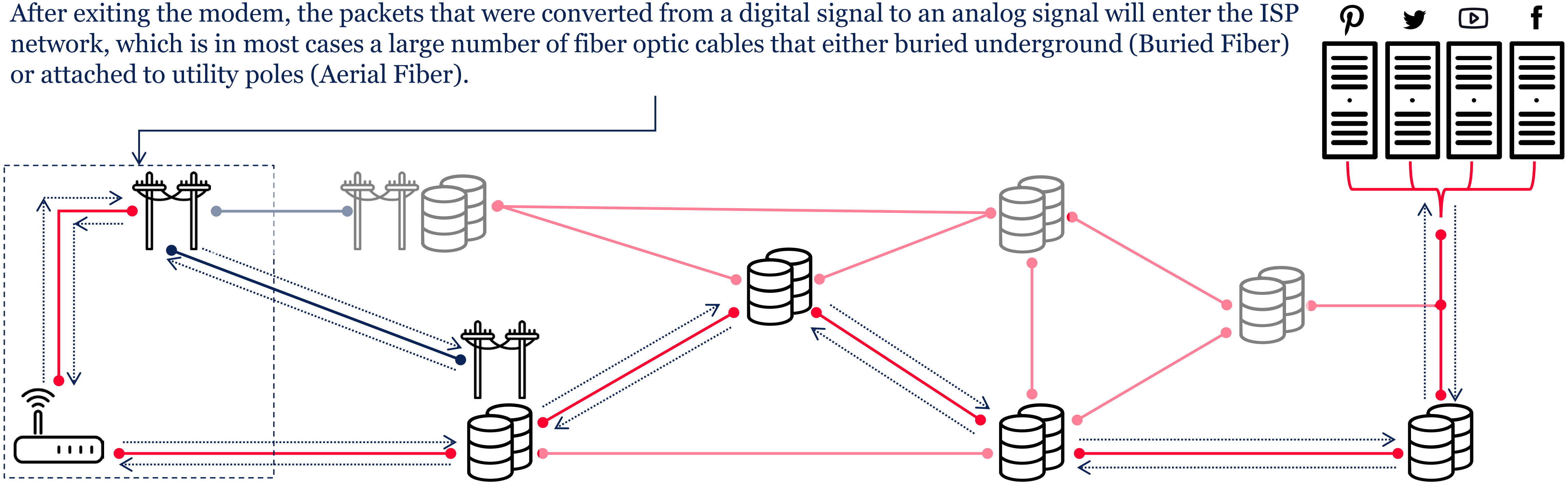
- When an Internet user is trying to access a web site, the first thing the computer will initiate is a communication with the server hosting the website located in a data center by sending a request.
- This "request" is a data that will be translated to a series of **1**s and **0**s (computer language), then will be chopped into chunks called packets.

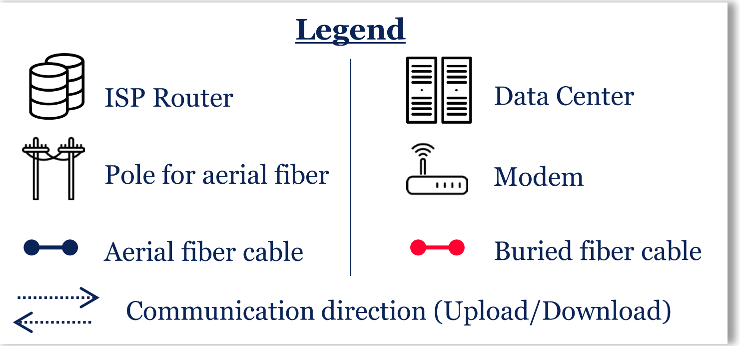


- Each packet will be sent to the wi-fi router via either wireless or cable (ethernet), then eventually, will exit the router to the modem and then to the ISP fiber or coaxial network towards the data center location.
- The data center, which can be across town or across the world from the end-user, has the requested web page stored inside it. Once the server gets a request to access a particular website, the data flow starts.

How does the Internet work ? (Cont’d)

After exiting the modem, the packets that were converted from a digital signal to an analog signal will enter the ISP network, which is in most cases a large number of fiber optic cables that either buried underground (Buried Fiber) or attached to utility poles (Aerial Fiber).





- Each packet will then move through multiple ISP networks, routers and switches towards the final destination where the packets will be reassembled into a coherent message (The original request).
- The network will choose the optimum route for the packet to reach the server based on the distance, the links capacity, and other factors.
- A separate message will go back through the network to confirm a successful delivery and right after, the data flow between the user and the server is established.

Broadband Key Terms

Broadband - The Basics

What is Broadband?

The term **Broadband** was introduced in the late 1990's and it commonly refers to **high-speed Internet** access that is always on and **faster** than the traditional dial-up access (Maximum of 56kBits/s) [1]. Broadband is accessed through various **high-speed transmission technologies** that allow the data to move faster.

How to access High-Speed Internet?

High-Speed Internet is delivered with one of two **Broadband** technologies. The **first technology** is **physical wire** and **cables** to connect the networks to the Internet, and this is called **Wired broadband** (e.g., Fiber Optic Cable). The other is **wireless technology** (e.g., Cellular 5G), and it's called **Wireless Broadband**. Each connection method is capable of providing high-speed Internet, but each differs in its own way.

How is FCC defining Broadband ?[2]

The Federal Communications Commission (**FCC**) defines basic broadband as transmission speeds of at least **25 Mbps** (megabits per second) **downstream** (from the Internet to the user's computer) and **3 Mbps upstream** (from the user's computer to the Internet). Infrastructure Investment and Jobs Act (IIJA) defines **underserved** broadband as an Internet speed of less than **100 Mbps downstream** and **20 Mbps upstream.**

[1] *Types broadband connections*
[2] *Internet speeds are measured at the end-user location (Last Mile)*

Middle Mile & Last Mile

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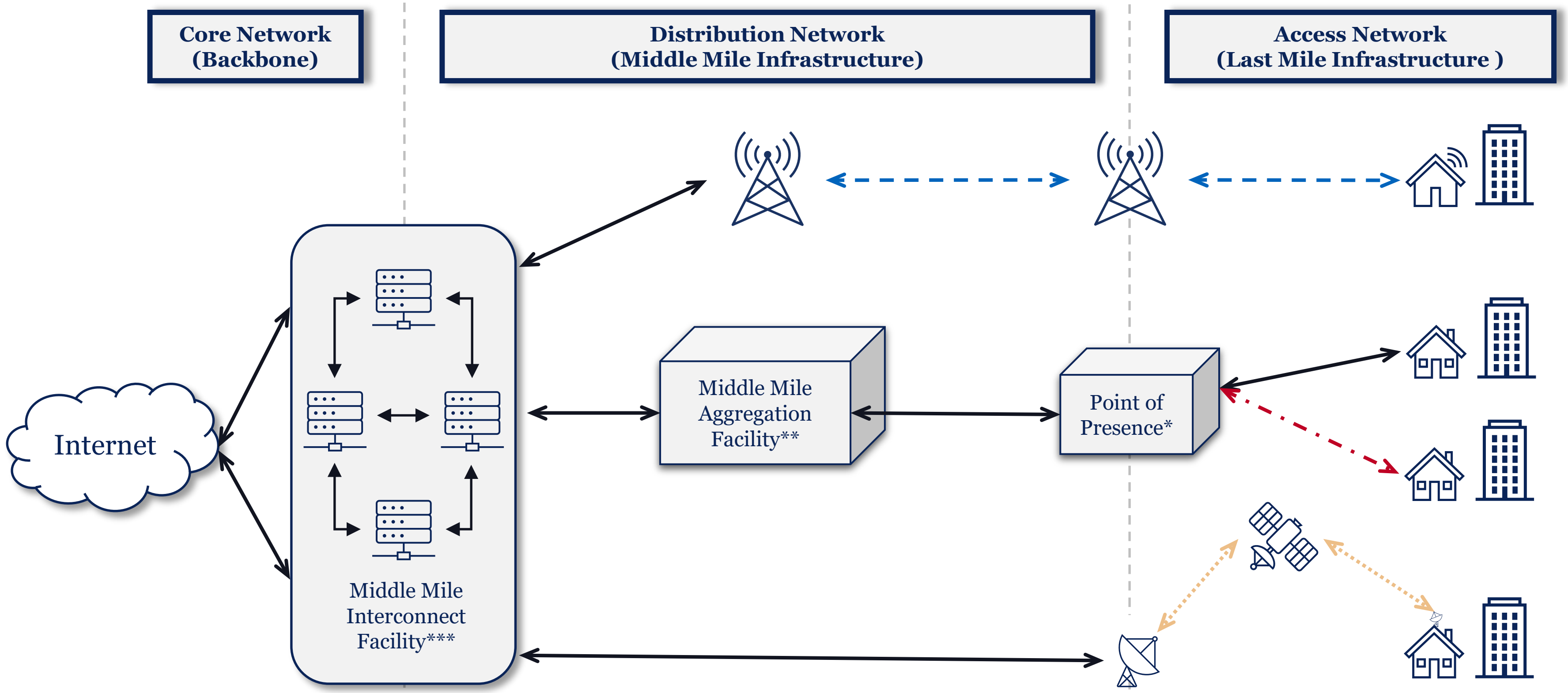
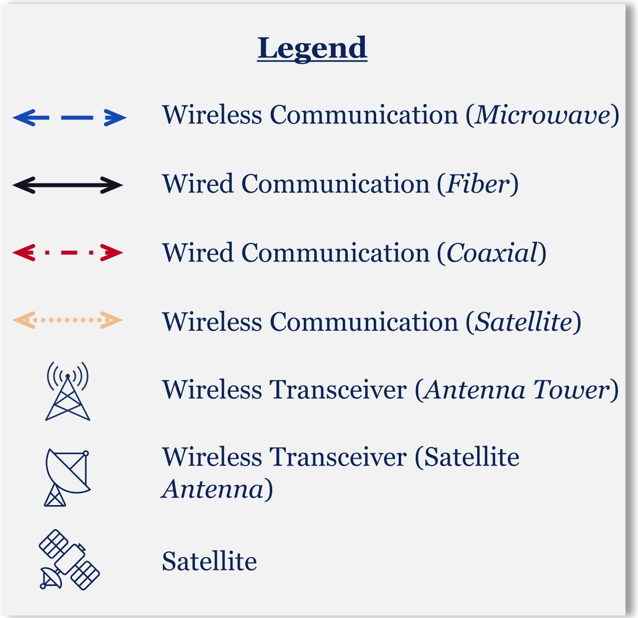




***Point of Presence(POP):** Demarcation point, access point, or physical location at which two or more networks or communication devices share a connection.

****Example of Middle Mile Aggregation Facility** is An **Internet Exchange Point** (**IXP**), which is a physical location through which Internet infrastructure companies such as ISPs connect with each other.

*****Example of Middle Mile Interconnect Facility** is a **Data Center**, which is a facility responsible for driving Internet content delivery and managing network resources.

Interconnected networks that transmit data between and across countries and continents

Middle Mile

The electronics and circuitry that carry a signal from interconnection points and aggregation facilities to a Central Office or Point of Presence.

Last Mile

The electronics and circuitry that deliver the Internet service to a household.

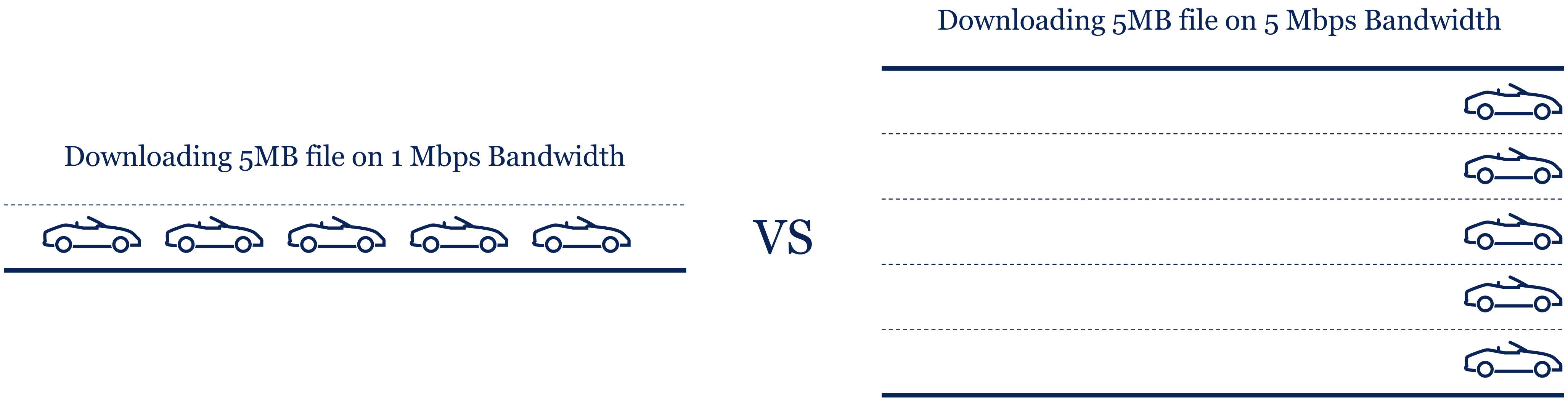
NTIA

Bandwidth

Bandwidth determines the **amount** of information that can be transmitted across a given path in a given **unit of time**. In other words, **bandwidth** is the size of the medium used to transmit data. The **larger** the size the **more** data you can transfer.

Bandwidth Analogy

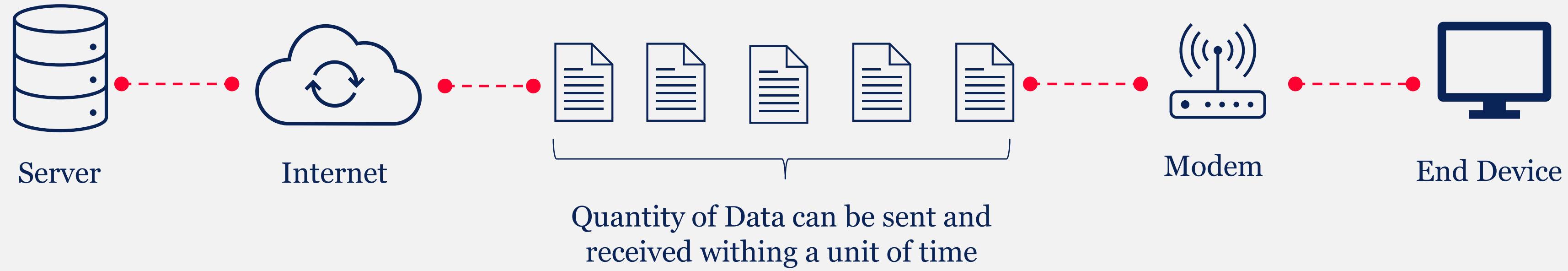
The best way to explain bandwidth is to use an analogy (*See the figure below*). Think of your bandwidth like a highway, and your data as cars that travel the **same speed**. The more lanes you have on the highway, the more cars can travel at a time – it will take 5 cars longer to get to their destination on a 1-lane road than it would on a 5-lane highway.



Throughput & Latency

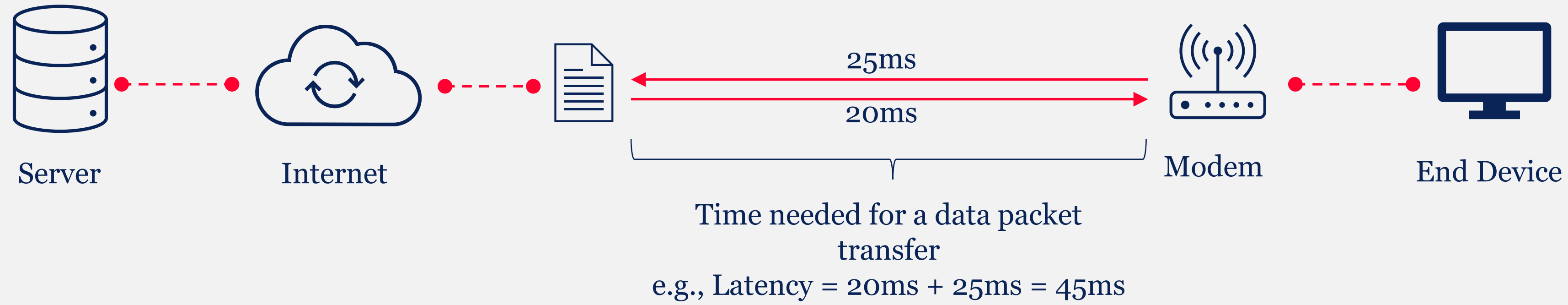
Throughput

The amount of a data that a system can transmit over a medium within a specified time. Measured in Megabits* per seconds (Mbps).



Latency

Network latency, sometimes called lag, is the term used to describe delays in communication over a network. It is a measurement of the time it takes to send data and receive a response.



* ***A binary digit*** *(bit) is the minimum unit of binary information stored in a computer system. A bit can have only two states, on or off, which are commonly represented as ones and zeros.*

Causes of Network Latency

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Distance
Latency can be caused by an excessive distance between the server/system making the request and the one that responds to it.

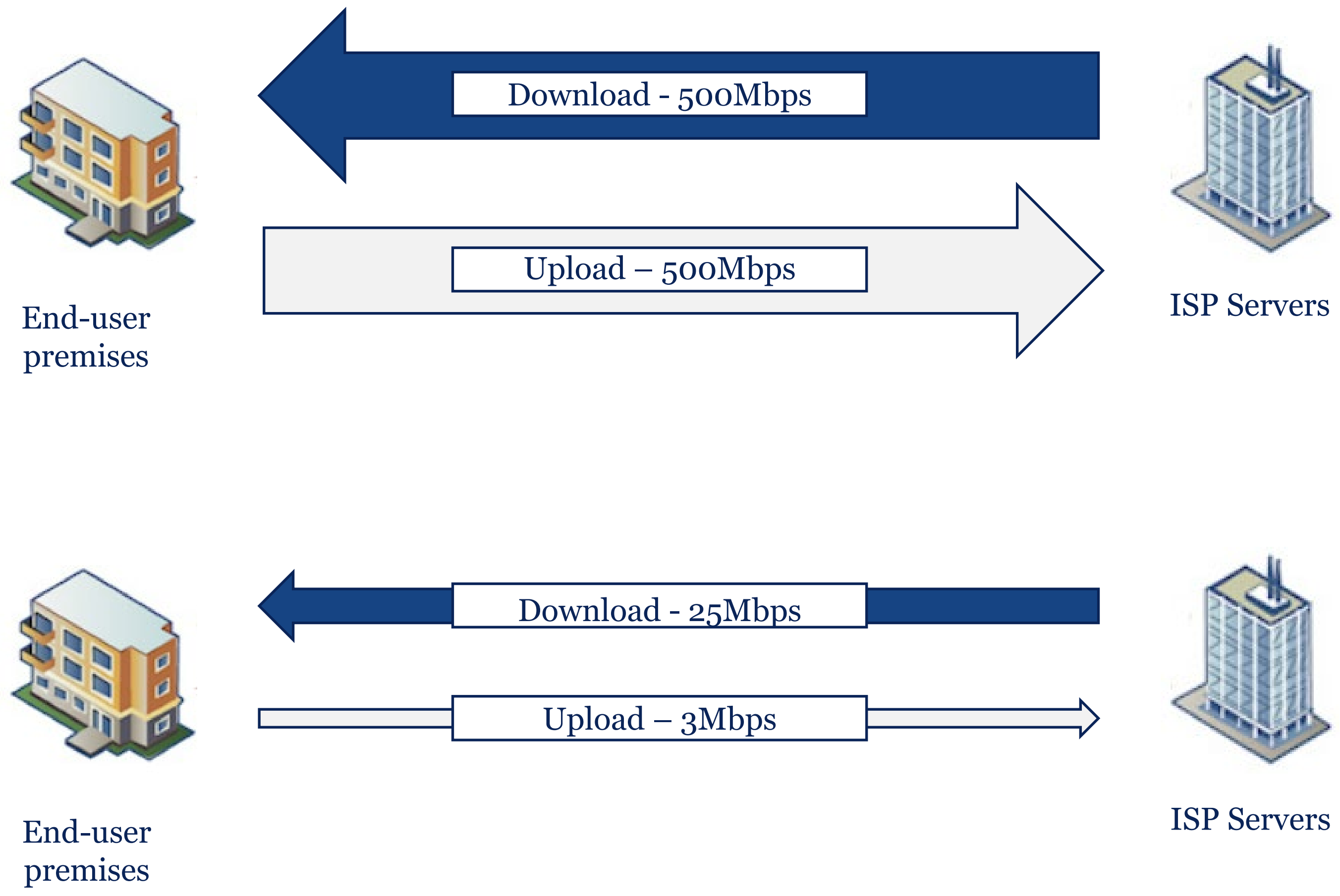
Bandwidth & Network Congestion
Network congestion happened when there's a lack of sufficient bandwidth to handle the existing amount of traffic, causing delays to the transmitted data and increasing latency.

Hardware Misconfigurations & Malfunctions
The check of hardware operation & configuration can be crucial in detecting latency causes. Malfunctioning or misconfigured equipment can lead to mis-matched connections between systems, which can add latency.

End-User issues
Network problems might appear to be responsible for latency, but sometimes excessive latency is the result of the end-user device being low on memory or the processing power needed to respond in a reasonable timeframe.

Physical issues
The physical medium used for communication (wires, fiber, wireless) can also be a source of latency. Cables can become damaged and wireless signal paths can become obstructed leading to loss of data or increased latency.

Symmetric vs. Asymmetric for Upload/Download



Symmetrical Communication

Symmetrical communication links are just as they sound. They have the same download and upload rates. For example, a 500/500 Mbps fiber Internet link offers download and upload speeds of 500 Mbps.

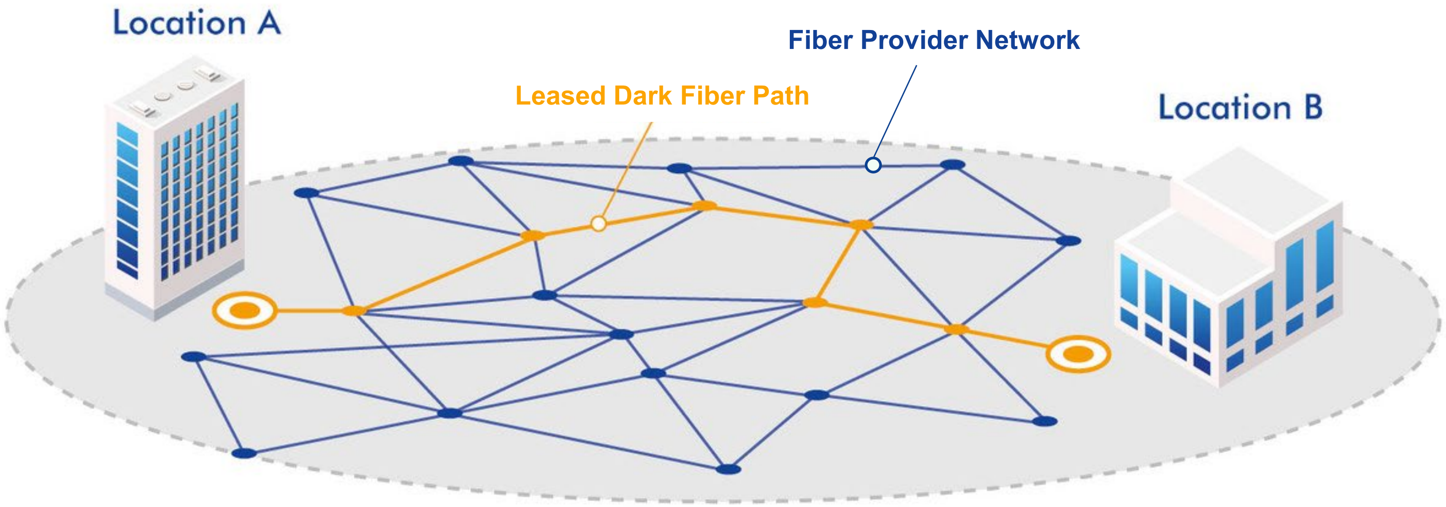
Asymmetrical Communication

Asymmetrical communication links, on the other hand, do not have the same download/upload rates. For example, 25/3 denotes a download speed of 25 Mbps and an upload speed of 3 Mbps. Asymmetrical data communication can make more efficient use of bandwidth than symmetrical data flows, since generally, most users will download more data than they upload

What is Dark Fiber ?

Dark Fiber

- Dark fiber refers to optical fiber infrastructure that has not yet been lit (**lit fiber*), meaning it is installed but is not yet being used (no data transmission).
- Dark fiber is rented by broadband providers who need to control their own network, so instead of leasing a service, they lease infrastructure that allows them to build their own network with their own equipment.
- Dark fiber gives clients the capacity to increase bandwidth as needed without paying any additional monthly costs and decreases dependence on carrier response times during events and for upgrades.
- Dark fiber is usually priced per strand per mile for a set period. The dark fiber providers often offer their client the option of an *indefeasible right of use (IRU)*** which can range between 20 to 30 years, paid upfront along with annual payments for maintenance.



Lit Fiber: This term is the opposite of dark fiber and refers to a fiber optic cable that is active and able to transmit data.*
*** **Indefeasible Right of Use (IRU)** : A contractual agreement (temporary ownership) of a portion of the capacity of a fiber optic cable.*

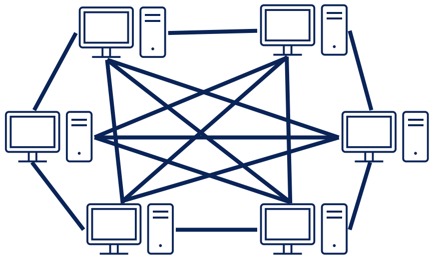
Visualization: panda com direct – Dark Fiber check

Network & Connectivity

Network Topologies

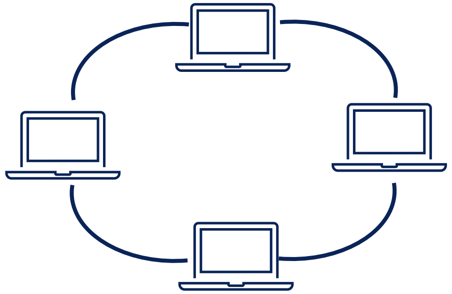
The term network topology describes how devices are connected to each other within the network. It describes how many connections each device has, in what order, and what sort of hierarchy. Typical network configurations include **mesh topology**, **ring topology**, **star topology**, and **tree topology**. Each topology has a different level of fault tolerance.

Mesh Topology



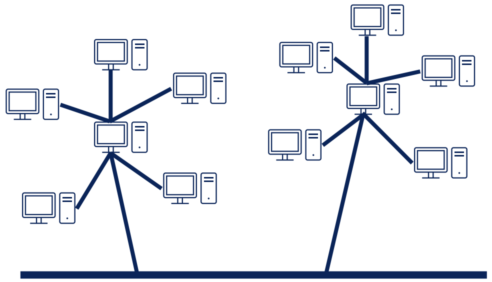
The topology in each node is directly connected to some or all the other nodes present in the network. This redundancy makes the network highly fault-tolerant, but the escalated costs may limit this topology to highly critical networks.
High Redundancy

Ring Topology



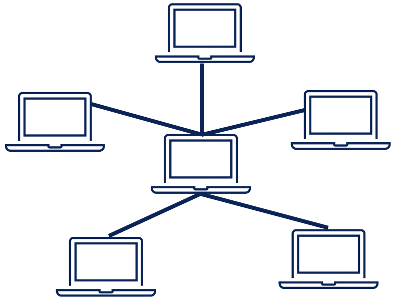
All network nodes are connected sequentially to a backbone, except that the backbone ends at the starting node, forming a ring. The failure of one node will result in changing the direction of the data traffic since the topology is Bi-directional .
High Redundancy.

Tree Topology



A root node is connected to two or more sub-level nodes, which themselves are connected hierarchically to sub-level nodes. Physically.
Medium Redundancy.

Star Topology



Also known as hub and spoke. All the nodes in the network are connected to a central device like a hub or switch via cables. Failure of individual nodes or cables does not necessarily create downtime in the network, but the failure of a central device can.
Low Redundancy.

Network Management Best Practices

What is Network Management?

Network management refers to a system consisting of processes, tools, and applications that help in the administration, operations, and maintenance of a network infrastructure. Network management systems collect and assist in analysis of network performance data, which engineers and administrators use to maximize availability, improve network performance, and ensure reliability and network security. The following are the Network Management Best Practices:

Understanding your Network

The first step is to understand your network- how it is designed, configured, how devices are connected, and how data flows within it. A clear understanding of the following is necessary:

- Network Topology
- Network Devices
- The OSI Model

Knowing and Implementing Network Security

The next step is to gain an understanding of the network defenses, i.e. the security controls that are available and those that are already in place. Implementing Tried and tested measures that establish a functional and effective security posture for dealing with common security threats.

Identifying & Tracking Devices, and Systems

Create a map of the network infrastructure highlighting the critical devices, systems, and software that form the network core.

Tracking network usage helps identify bandwidth-eating technologies, and devices which can cause sluggishness and connectivity problems for everyone else.

Creating Redundancy to Avoid Network Failures

The network is a complex architecture consisting of hundreds of pieces of hardware, software, systems, and protocols. Failure can occur in one of the core network components and bring down a whole system.

Network failures can be avoided by creating network redundancy in components that are most likely to fail

Understanding your Network Compliance Requirements

Knowing the compliance requirements of your business will help you set expectations and manage your network better.

Redundancy vs Resiliency in Broadband Networks

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Redundancy
The deployment or provisioning of duplicate devices or systems in critical areas. Redundant devices can operate in active-active, or active-standby; but the goal is the same: Minimize operational impact of device failures.

Resiliency
The ability to recover, converge or self-heal to restore normal operations after a disruptive event. Resiliency is enabled by the proper implementation of redundancies.

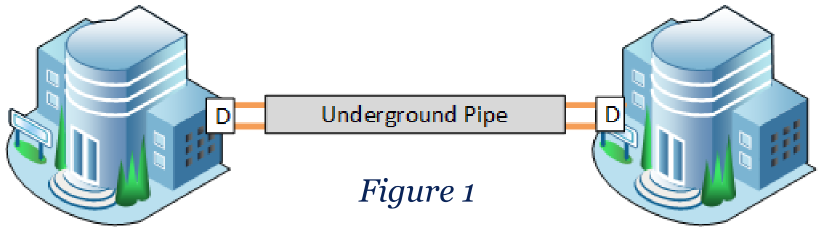


Figure 1

Figure 1 shows a redundant fiber optic connection between two buildings. This network is considered redundant but not resilient as there are still two single points of failure that would render the redundant fiber optic cable useless: Demarcation points & underground pipe

Legend
Fiber Optic Cable
D Demarcation Point

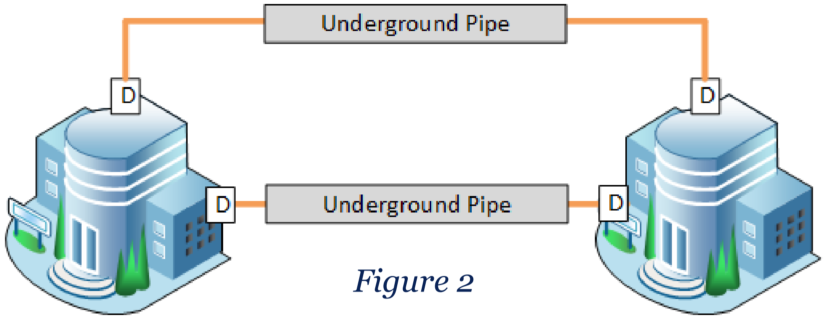


Figure 2

Figure 2 shows a redundant fiber optic connection between the two buildings. This network is considered redundant and resilient as it has two physically separated demarcation points in each building. An event at any one demarcation point will not affect the other.
Routing each fiber optic cable via a physically separate conduit, over a separate path, will ensure that those cable finders can't take the service out by cutting a single underground pipe.

***Note** : It's critical that as much distance as possible geographically separates the underground pipes. Putting them right next to each other would obviously defeat the purpose.*

Visualization: VOLOGY (ATSG)– [redundancy-vs-resiliency]

OSI Model

OSI Model

The Open Systems Interconnection (OSI) model is a conceptual model that describes the universal standard of communication functions of a telecommunication system or computing system, without any regard to the system's underlying internal technology and specific protocol suites. The OSI model has seven layers described below, and helps:

- Determine the required hardware and software to build their network.
- Understand and communicate the process followed by components communicating across a network.
- Perform troubleshooting, by identifying which network layer is causing an issue and focusing efforts on that layer.

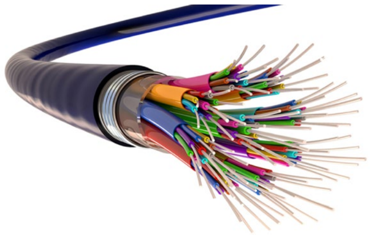
BEAD Infrastructure's focus

Middle Mile Infrastructure's focus

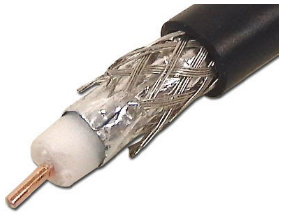
Physical Layer - L1	Data Link Layer – L2	Network Layer – L3	Transport Layer – L4	Session Layer – L5	Presentation Layer – L6	Application Layer – L7
Transmits raw bits stream over the physical medium (Wired or wireless)	Establishes and terminates a connection between two physically-connected nodes on a network	Decides which physical path the Data will take	Transmits Data using transmission protocols including TCP and UPD	Maintains connections and is responsible for controlling ports and sessions	Ensures that Data is in a usable format and is where Data encryption occurs	Human-Computer interaction layer, where application can access the network services

OSI Model – Physical Layer L1

The **physical layer** is responsible for the physical cable or wireless connection between network nodes. It defines the connector, cable or wireless technology connecting devices. **Layer 1** is responsible for encoding and transmission of the raw data over a medium.
Example of Wired and Wireless mediums associated with Physical Layer :

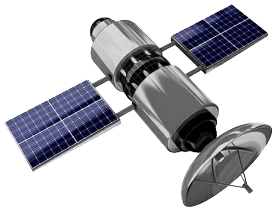


Fiber Optic
Transmits data via light waves. Optical cable currently has the highest capacity and distance of any transmission medium.



Coaxial Cable
Transmits data over longer distances than other copper cables. Coax is most commonly used in cable TV networks.

Twisted Pair Cable
Commonly used for telephone and Ethernet. Usually seen inside houses



Satellite
Transmits data via radio waves through an orbiting satellite. Traditionally used for remote locations.

Microwave
Transmits data via radio waves over a clear line of sight

OSI Model – Data Link Layer L2

The **data link layer** establishes and terminates a connection between two physically-connected nodes on a network. It breaks up packets into frames and sends them from source to destination. This layer is composed of two parts—Logical Link Control (LLC), which identifies network protocols, performs error checking and synchronizes frames, and Media Access Control (MAC) which uses MAC addresses to connect devices and define permissions to transmit and receive data.

Network Switch is the device associated to Data link Layer

A network switch connects devices within a network and forwards data frames to and from those devices. Unlike a router, Layer 2 switch only understands communication with devices directly connected to it; Layer 2 has no concept of sources or destinations "farther away" on the network.

48 ports Network switch

Network switches can operate at either OSI layer 2 (the data link layer) or layer 3 (the network layer). Layer 2 switches forward data based on the destination MAC address. Layer 3 switches forward data based on the destination IP address, effectively making them routers. Some switches can do both, operating at both OSI layers 2 and 3.

Network Switch Symbol

OSI Model – Network Layer L3

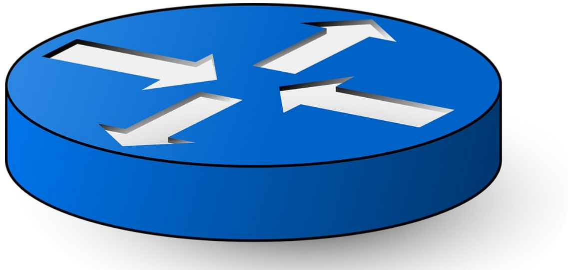
The **network layer** is responsible for the end-to-end delivery of data between the originating device and the final destination. Routers forward packets by discovering the best path across a physical networks. The network layer uses network addresses (typically Internet Protocol addresses) to route packets

Network Router is the device associated to Network Layer

A router is a device that connects two or more packet-switched networks or subnetworks. Routers manage traffic between these networks by forwarding data packets towards their intended destination IP addresses.

In order to direct packets effectively, a router uses an internal routing table — a list of paths to various network destinations. The router reads a packet's header to determine where it is going, then consults the routing table to figure out the most efficient path to that destination. It then forwards the packet to the next network in the path.

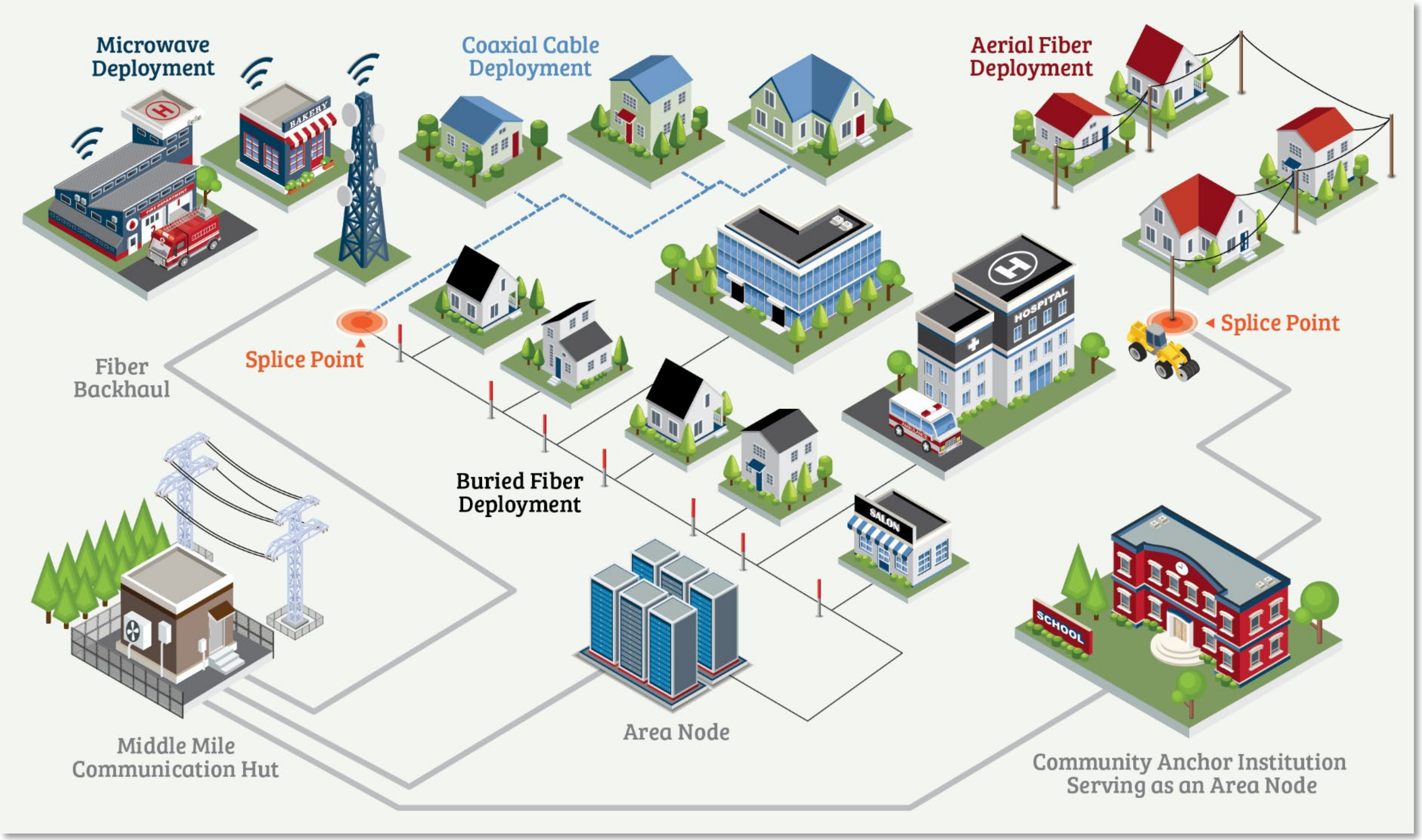
Enterprise Router



Network Router Symbol

Broadband Connection Types

Broadband connection types



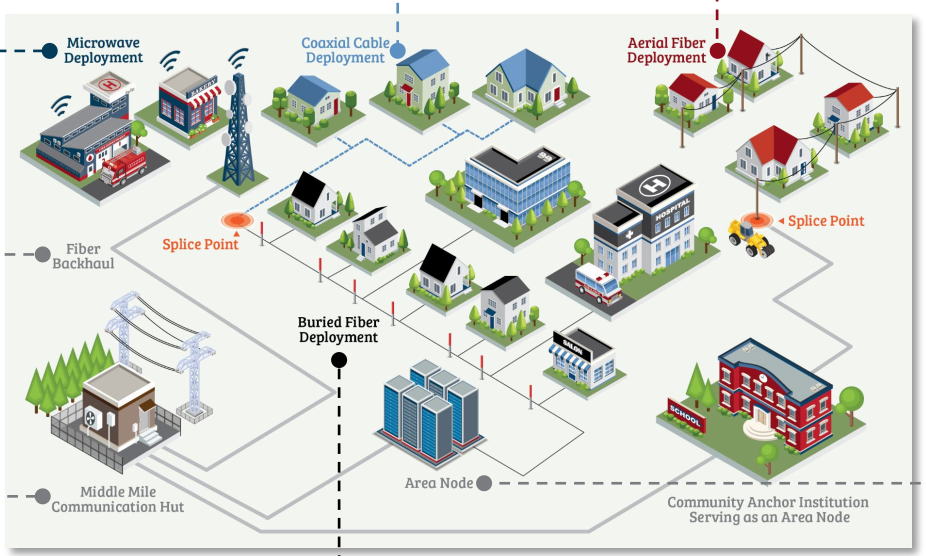
Broadband connection types

A system that operates on Mid-to-high radio frequency signals and connect two locations that have a clear line of sight

Originally installed for cable TV but can be also used to transmit Internet services. The communication is typically asymmetrical, with fast download and slow upload

Cables are deployed using existing pole infrastructure. Typically, more cost effective, but may be less suited for areas with extreme weather

Fiber optic cables deployed and serving as a connection between the access network (Last Mile) to the core network (Backbone).



A location serving as a central point for distribution of communication services. The facility serves multiple buildings.

A remote point in the fiber optic cable system connecting fiber optic cables to the distribution system. *(e.g., Data Center, Teleco central Office)*

Fiber Optic cables are directly buried or installed in underground ducts. Typically, more expensive to deploy, but may be better suited for areas with extreme weather

Aerial vs Buried Fiber optic cable – Pros & Cons

	Buried Fiber Optic Cabling	Aerial Fiber Optic Cabling
	Buried cabling is the opposite of aerial cabling, as it's buried under the ground in pipes or conduits rather than outside along utility poles. This can protect them from the bad weather that aerial cabling must deal with, but it can be costly.	*Also known as overhead cabling, aerial cabling installs the Fiber Optic cables typically along a line of utility poles. The cables connections are kept away from any foot traffic but are more vulnerable than buried cable.*
Pros	– Protected from extreme weather and damage – Can lease pre-existing conduits/pipes – Preferred by local planning authorities	– Easily modified if you need to add more cabling – Can be more cost effective if existing utility poles can be used. – Often used un rural environment that lack local planning authorities like that of large towns or cities
Cons	– Can be expensive due to how deeply cables need to be buried or geology (e.g., rock or hard clay in the ground) – Risk of cables being dislodged due to an excavation – Expensive to repair	– Susceptible to bad weather (*e.g., extreme winds, ice, and tree damage*) – Takes time to install due to make-ready requirements – Difficult to install in cities or towns due to local planning authorities' guidelines

Broadband Economics

Costs | Typically Segmented Into Two Key Categories

INTERNET FOR ALL

Capital Expenditure (CapEx)

Dollar cost to build the network asset

- *Typically, a large, upfront cost which is depreciated over the useful life of the asset for accounting purposes.*
- *Can include material, land, labor for construction and connection, engineering, permitting, upgrades and replacements, and construction equipment.*

Operational Expenditure (OpEx)

The day-to-day (ongoing) cost to run and maintain a network to provide services

- *Can include power, network maintenance, middle mile and/or core Internet transit fees (if any), sales and marketing, customer support, rent, and other business operation expenses.*

In the context of IIJA, the Broadband Equity, Access and Deployment (BEAD) program in effect provides a significant CapEx subsidy. Therefore, the key cost considerations for providers are their **remaining CapEx costs (match amount) and ongoing OpEx once the network is operational.**

Brownfield Builds Can Reduce Costs

Leveraging Existing Infrastructure Can Lower Costs

To manage costs, providers can work with state and local entities, as well as private entities, to leverage existing infrastructure or planned construction work in relevant areas (e.g., transportation) to lower mobilization and permitting costs.

Brownfields

are networks built by extending or upgrading an existing network, thus leveraging existing infrastructure to reduce deployment costs

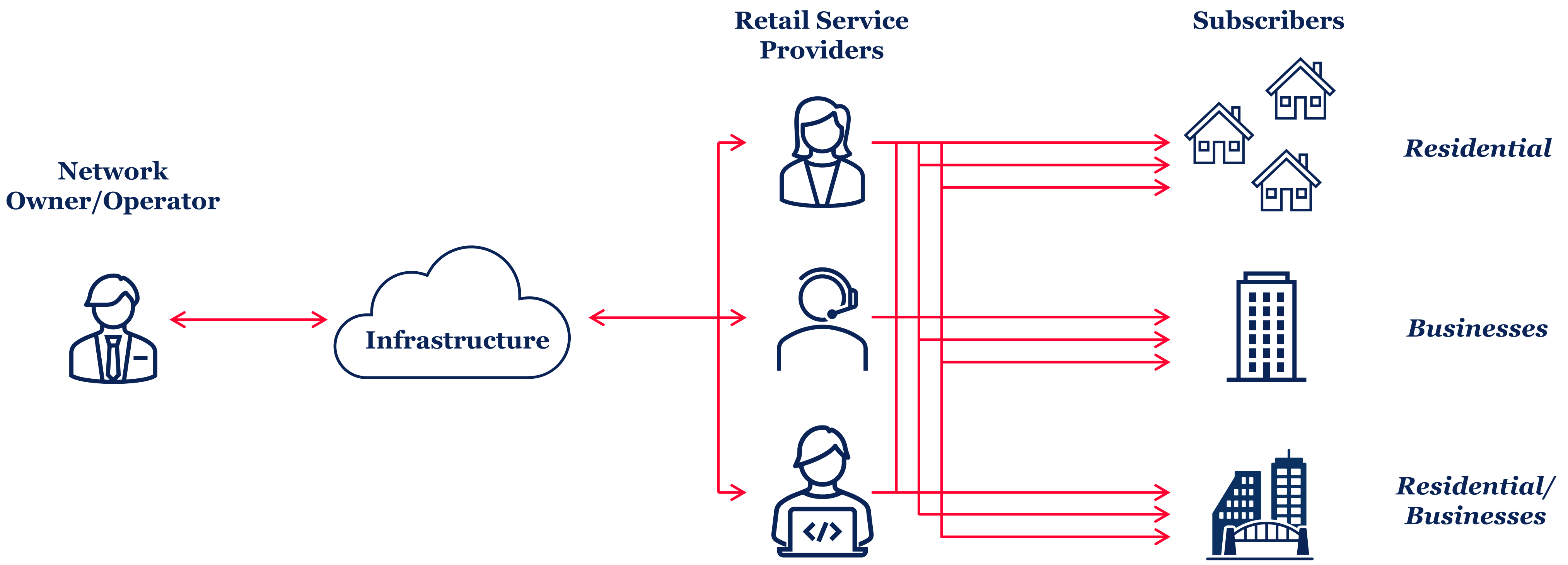
Greenfields

are networks built entirely from scratch and thus deployment costs are typically higher

The majority of CapEx tends to be in civil works (e.g., digging, plowing, construction, permitting), and then in network materials (e.g., fiber) and electronics

Open Access

Open Access networks, the same physical network infrastructure is utilized by multiple providers delivering services to subscribers. The **Open Access business model** has been drawing attention globally as governments and municipalities find the concept of offering competition between providers and the freedom of choice for the subscriber is essential. It has also proved to be a **feasible** way to connect **rural areas** where service providers might have a hard time generating **enough revenue** to justify investing in their own network infrastructure.
Unlike more common **network arrangements** (where one company, owns, operates, and provides services on the network), open access **separates** the **physical network** from the **services.** An entity owns the network and may contract with a different firms to operate it; multiple ISPs will provide services on it. Below is a diagram of the main component of an Open Access network:



Example of an Open Access Arrangement

INTERNET FOR ALL

Pay wholesale fees

Pays for Service

Network Owner

Funds construction. Contracts and pays operators of the network. No direct contact with retailers or End Users.

Network Operator

Hired by Owner to oversee construction, maintain the network and be responsible about sale and support of the network services on a wholesale basis with retailers. Operators work with retailers and do not have contact with End Users.

Retailers

(e.g., ISPs)

The retailer buy raw transit on the network from the operator and sells consumer services such Internet & TV to the End User. Retailers are responsible for marketing their services and provide customer service.

End User

(e.g., Residential)

The End Users are the customers at the retail level , who buy services for their homes or businesses. End Users get billed by the retailers and have no sight of the Network owners or operators.

Disclaimer: *The information above is strictly used as an example and does not define or rule how open access arrangements work.*

NTIA

Fiber Optics Deployment Costs

		Aerial	Underground
Cost per mile (CPM)	Typical range	**$32,000 - $78,500**/mile[1]	**$51,000 - $220,000**/mile[2]
	Other common cost drivers	*Labor wage, fiber cable cost, brownfield vs. greenfield*	
Cost per home passed (CPHP)	Typical range – Dense	**$500 - $1,000**/home passed	**$700 - $2,200**/home passed
	Typical range – Sparse	**$2,100 - $4,300**/home passed	**$3,400 - $5,900**/home passed
	Typical range – Extremely rural	> **$6,400**/home passed	> **$10,000**/home passed
	Key cost driver	*Passing per mile due to density*	
Cost per drop	Typical range – Dense	**$700 - $1,600**/drop	
	Typical range – Sparse & rural	**$1,500 - $4000**/drop	
	Key cost driver	*Aerial vs. underground drops; length of drops*	
Other network costs per home connected[3]	Central & distribution electronics per home connected	**$400 - $850**/home connected[4]	
	Customer premises equipment (CPE) per home connected	**$300 - $675**/home connected[5]	
	Middle-mile / backbone construction per home connected	**$300** (urban) - **$900** (rural)/home connected	

Note: All cost estimates represent "greenfield" development to individual homes, i.e., not discounting for "brownfield" cost savings or deployment model to multi-dwelling units (MDUs).
1. Up to $61,000 in extreme scenarios; 2. Up to $400,000 in extreme scenarios. Wide range reflects vastly different build costs on different topographies; 3. Assume 35% take rate; higher take rates would lower cost; 4. There is typically economies of scale with central equipment cost—adding new users may incur less marginal cost; 5. CPE costs include fees and materials for installation.
Sources: Rios Partners / BCG expert interviews & analysis, CTC studies, NRTC report, NCHeartGigabit

Fiber Optics Deployment Costs (cont'd)

INTERNET FOR ALL

There are four potentially relevant network rollout archetypes based on unserved" and "underserved" populations, with implications on costs.

	Unconnected urban	Denser rural	Sparse suburb/exurb	Rural and remote
Characteristics	• Medium to high density • Urban cores	• Medium density • From near urban cores to highly rural	• Very low density • In or near urban cores	• Very low density • Highly rural and isolated
Unserved segment	• 14%	• 3%	• 37%	• 46%
Underserved segment	• 12%	• 17%	• 34%	• 37%

Sources: Rios Partners / BCG expert interviews & analysis; BroadbandNow OpenData; FCC Form 477 Data (retrieved from BroadbandUSA interactive map) and FCC staff estimate (source); 5-year ACS Survey (2015-2019) from Census.gov

Fiber Optics Deployment Costs (cont'd)

	Unconnected urban	Denser rural	Sparse suburb /exurb	Rural and remote
Build-out method	Rely heavily on underground except where poles are available	Likely rely on aerial	Likely rely on aerial	Rely heavily on aerial, if FTTH deployment at all
Estimated typical aerial costs	**CPM**: $78,500 and up **CPHP**: $500 - $800	**CPM:** $47,500 - $63,000 **CPHP:** $600 - $1,000	**CPM:** $32,000 - $47,500 **CPHP:** $2,100 - $4,300	**CPM:** $32,000 - $47,500 **CPHP:** > $6,400
Estimated typical underground costs	**CPM:** $110,000 - $220,000 **CPHP:** $700 - $2,200	**CPM:** $75,000 - $110,000 (up to $135,000 in hard terrain) **CPHP:** $950 - $1,700 (up to $2,100 in hard terrain)	**CPM:** $51,000 - $64,000 (up to $135,000 in hard terrain) **CPHP:** $3,400 - $5,900 (may exceed $10,000 in hard terrain)	**CPM:** $51,000 - $64,000 (may exceed $400,000 in extreme terrain) **CPHP:** > $10,000

CPM = *Cost Per Mile*

CPHP = *Cost Per Home Passed*

FTTH = *Fiber To The Home*

sources: Rios Partners / BCG expert interviews & analysis

THANK YOU

Any Questions?