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BROADBAND NETWORK DEPLOYMENT ENGINEERING

AN OVERVIEW

Overview

The Bipartisan Infrastructure Law is historic in its size – the largest ever investment in broadband, rail and transit, clean energy, and water, including $65B to help close the digital divide through broadband deployment, improved affordability, and digital equity.

Addressing persistent barriers to universal broadband deployment in unserved and underserved areas requires a strong understanding of the different components of a broadband Internet network. This brief provides an **overview of broadband deployment engineering**, covering network architecture, infrastructure elements, business models, and technologies, as well as the relationships between each.

Network Architecture

Broadband networks transmit and receive data between end users (e.g., households, businesses, anchor institutions) and interconnection points of the core Internet, allowing users to connect to the Internet's global resources. This requires data to flow seamlessly over three types of networks: **core Internet backbone**, **middle mile**, and **last mile**. It is critical to understand the functions and interactions of each, as they form the foundation of a comprehensive network that enables Internet service provision. To close the digital divide, the IIJA includes programs to fund the deployment of both middle mile and last mile networks.

CORE INTERNET BACKBONE

The core Internet backbone is comprised of interconnected networks that transmit data between and across countries and continents. To ensure reliable service, backbone networks build in **redundancy** through **path diversity**. They also contain critical databases and standards that ensure effective and secure Internet operation.

Global telecommunications and technology companies typically own and operate backbone networks, which principally use terrestrial and submarine fiber-optic cable for connectivity.

MIDDLE MILE

Middle mile networks connect an area node with the core Internet. The area node is a local connection point for the last mile network elements. Where feasible, middle mile networks should employ path diversity to increase redundancy. In addition, these networks need sufficient capacity to carry the traffic from the local network without **contention**.

In the U.S., large Internet service providers and specialized long-haul companies typically own and operate middle mile networks, which deploy fiber-optic cable or, in some cases, wireless technologies.

DEFINITION OF KEY TERMS

Contention: Competition for bandwidth. A *contention ratio* is the potential maximum demand on a network compared to actual bandwidth available; a lower ratio signifies better service, while a higher ratio signals oversubscription and reduced quality of service.

Path diversity: The principle that a network has multiple potential physical paths between interconnection points and the backbone to increase redundancy.

Redundancy: A characteristic of a network that has multiple paths or devices that help sustain network availability in the event of a single path or device failure.

LAST MILE

Last mile networks, also called access or local networks, connect end users via an area node to a middle mile network, which enables connection into the core Internet backbone. Unlike backbone and middle mile networks, which aggregate traffic from multiple customers (e.g., Internet service providers, other network owners), last mile networks provide connectivity between end users and an area node.

A range of organizations own, operate, and provide Internet services over last mile networks, including large and small Internet service providers, cable companies, municipalities, and rural electric or telephone cooperatives. Last mile networks use many technologies to transmit data (see Network Technology section).

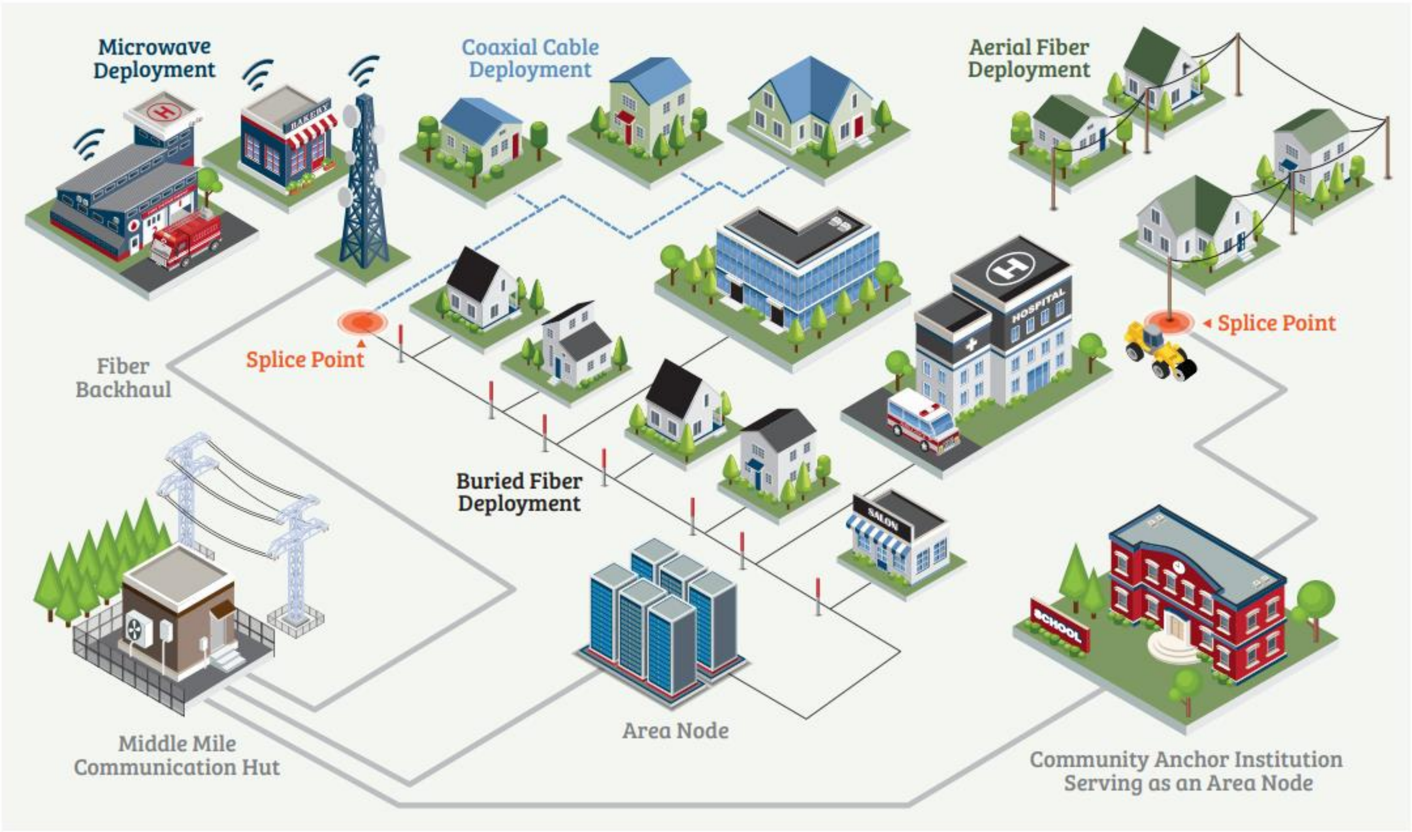

Figure 1. A last mile network with multiple technologies deployed connected to a middle mile network at an area node

Network Infrastructure Elements

Broadband networks consist of both passive and active elements. When integrated, they enable the provision of Internet service. It is critical to understand the purpose of each, as decisions on materials and network design will shape deployment economics and logistics, as well as network performance and path diversity.

PASSIVE INFRASTRUCTURE

Passive infrastructure is the physical layer of material needed to enable connectivity. For fixed broadband, examples include fiber-optic and copper cables, ducts, conduit, utility poles, adaptors, and splitters. For wireless broadband, examples include towers, antennas, buildings, fiber conduit, and power equipment.

ACTIVE INFRASTRUCTURE

Active infrastructure refers to the electronic elements that enable passive infrastructure to transmit data by accurately routing it, changing the medium (e.g., optical to electrical), amplifying it, or adding value in other ways. Examples include fiber-optic terminals, routers, servers, and switches.

Network Business Models

In the U.S., a range of network business models are available. For network owners, operators, and Internet service providers, the model they use will impact deployment costs, market dynamics, and competition.

Network business models exist on a spectrum. On one end, **vertical integration** is where one entity owns the passive infrastructure, owns and operates the active infrastructure, and provides Internet services over the network to end users. On the other, **open access** is where an infrastructure owner provides wholesale access to the network for lease on a non-discriminatory basis but does not themselves provide residential services to end users. In between are a range of **infrastructure sharing** models in which a network owner and/or service provider makes portions of their passive and/or active infrastructure capacity available for use to other entities (e.g., wholesale peering and transit).

	Vertical Integration	Infrastructure Sharing	Open Access
Owners	1	1 or more	1 or more
Owners providing services	1	Variable	None
Providers operating	1	1 or more	Many
Competitive use of facilities	None	Limited	Encouraged

Major Internet backbone providers typically utilize an infrastructure sharing model in which they exchange traffic freely between entities, called settlement-free peering, or charge a transit fee to other entities for access. Middle mile network models are more varied, and there are successful models across the spectrum in the U.S. Finally, owners of last mile networks typically opt for vertical integration, though a handful of open access last mile networks exist in the U.S.

Spotlight on Different Business Models

Dakota Carrier Network (DCN) is a middle mile network that utilizes an infrastructure sharing model. Founded in 1996 by 15 local telephone cooperatives and companies, the DCN connects each owner's last mile network to the core Internet backbone and sells wholesale access to other entities.[1] Due in part to DCN's efforts, the percentage of North Dakotans with access to 1,000/100 Mbps broadband Internet is 18 percent higher than the U.S. average.[2]

Northwest Open Access Network (NoaNet) is an open access middle mile network owned by nine public utility districts (PUD) in Washington State. Over 100 retail Internet service providers lease a connection to NoaNet's network to provide Internet services to 170 communities and 200 anchor institutions.[3]

Network Technology

Over the past three decades, Internet service providers have pursued a variety of technologies to provide end users with affordable, reliable, high-speed broadband. It is important to know how these technologies function and the contexts in which they operate, as they greatly influence the quality of Internet service provided. Speed, latency, reliability, and prevalence can vary based on several variables:

- **Distance to area nodes**
- **The complexity of the design (e.g., the amount of equipment and splice points)**
- **The number of end users on the network**
- **Impediments to transmission (e.g., line-of-sight obstructions, adverse weather)**

1. Institute for Local Self-Reliance, "How Local Providers Built the Nation's Best Internet Access in Rural North Dakota" (2020).
2. Federal Communications Commission, "Compare Broadband Availability in Different Areas" (2019).
3. NoaNet.net, "Our Story" (2020).

Terrestrial broadband	Considerations in unserved and underserved areas
Fiber Transmits data as pulses of light through fiber-optic cable made from glass or plastic	*Speed*: Fastest download and upload speeds on average *Latency*: Very low *Reliability*: High except for risk of damage to aerial and buried lines *Prevalence*: Increasing as Internet service providers replace copper; has become default for new builds or upgrades in urban areas and many rural areas
Hybrid Fiber Coaxial (HFC) Transmits data through fiber that feeds into coaxial lines to the end user	*Speed*: Varies based on number of end users on coax segment; upload speed often slower than download speed under DOCSIS *Latency*: Relatively low *Reliability*: High except for risk of damage to aerial and buried lines *Prevalence*: Common in most areas, though less widespread in rural areas
Digital Subscriber Line (DSL) Transmits data over existing copper phone lines	*Speed*: Slower on average; depends on length and quality of copper *Latency*: Relatively low *Reliability*: High except for risk of damage to aerial and buried lines *Prevalence*: Less common as fiber has supplanted it but it is often left in place
Wireless broadband	**Considerations in unserved and underserved areas**
Fixed Wireless Access (FWA) Transmits data over radio waves between two fixed points	*Speed*: Varies based on spectrum availability and potential congestion *Latency*: Very/relatively low; depends on design, spectrum, and enviro. conditions *Reliability*: May be lower in adverse weather (e.g., rain fade) over longer distances or with line-of-sight obstructions (e.g., high-density foliage) *Prevalence*: Available in many rural areas, especially with difficult terrain
TV White Space (TVWS) Transmits data over unused radio wave frequencies between TV channels	*Speed*: Relatively slow, though it is new and in the early stages of deployment *Latency*: Theoretically can be relatively low under ideal conditions *Reliability*: Can penetrate dense foliage, avoiding some line-of-sight issues *Prevalence*: Several pilot projects underway
Low Earth Orbit (LEO) Satellite Transmits data over radio waves using constellations of satellites <1k miles above earth	*Speed*: Relatively fast speeds (>100 Mbps) theoretically possible *Latency*: Relatively low but can vary as satellites move relative to end users *Reliability*: As a newer technology evolving rapidly, difficult to ascertain *Prevalence*: As a newer technology, unclear at this time
Geosynchronous Equatorial Orbit (GEO) Satellite Transmits data over radio waves using several geostationary satellites 22k miles above earth	*Speed*: Varies based on number of concurrent end users and satellite line-of-sight *Latency*: Relatively high due to longer distance radio waves must travel *Reliability*: May be lower in adverse weather (e.g., rain fade) or with line-of-sight obstructions (e.g., high-density foliage) *Prevalence*: Most common in remote areas

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