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Towards a connected nation: Exploring telecommunication technology ecosystems for effective, efficient, and economical deployment strategies

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Abstract

This article investigates the telecommunication technology ecosystem to formulate strategies for building a connected nation using effective, efficient, and economical combination of technologies. It examines both wireless systems (e.g., Microwave Transport Radio, Cellular Access Radio Systems, WiFi, Fixed Wireless Access, Satellite Systems) and wireline systems (e.g., Fiber Optics). The analysis evaluates each technology's inherent characteristics, benefits, challenges, cost, deployment ease, capabilities, scalability, and applications in urban and rural settings. Emphasis is placed on leveraging these technologies for various services, including voice, data, video, AI, emergency services, telemedicine, and robotic health operations in underserved and urban regions. A Scenario-Need-Technology Mix Matrix (SNTMM) is developed to assist service providers, governments, policymakers, program managers, and communities in selecting the appropriate technologies to meet their needs effectively and economically.

Keywords: Telecommunication; Connected Nation; Digital Divide, Rural connectivity; Broadband; Digital Divide; Wireless Communications; Cost

1. Introduction

A "connected nation" is one where the population has access to diverse telecommunication and information technology (IT) services, such as Internet broadband connectivity, mobile communication networks, digital banking, e-commerce and digital service platforms. Deploying telecommunication infrastructure varies in cost across different regions, making it crucial to understand community needs, geographical terrain, and the effective combination of technologies to deliver value economically [1][2].

1.1. Purpose and Scope of the Article

This paper analyzes the characteristics of various telecommunication technologies, including their deployment ease, supported applications, drawbacks, and combinations to provide timely, effective, efficient, and economical connectivity. While previous studies focused on analysing the impact of global digital divide, this paper examines the specific needs of communities and proposes technological solutions to meet these needs[3]. It explores the telecommunication technology ecosystem's role in shaping national connectivity, by providing insights into how leveraging various technologies can bridge the digital divide, and promote inclusive growth [11]. Emphasis is placed on deploying infrastructure in remote and rural areas, emergency services, telemedicine, and robotic health operations[12],[13],[14]. The article serves as a guide for policymakers, technology solution providers, planners, design teams, industry stakeholders, and researchers to create economical, inclusive, and technologically advanced connected nations[15].

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2. Methodology

The methodology outlines the systematic approach adopted to review telecommunication technologies, assess community needs, and determine effective deployment strategies. This is conducted in three main phases: Technology Review, Community Needs Assessment, and Strategic Analysis.

2.1. Technology Review

The first phase involves a comprehensive literature review of telecommunication technologies, including point-to-point microwave transport radio system, fiber optics, cellular (4G/5G) wireless systems, satellite/VSAT communications, and fixed wireless access. Sources include academic journals, industry reports, white papers, government publications, and technical standards documents, guided by keywords such as telecommunication technologies, deployment strategies, cost analysis, efficiency, broadband and digital divide. Data collection involves documenting each technology's characteristics (e.g., bandwidth, latency, reliability, coverage area, scalability) and analyzing their strengths, weaknesses, and capital expenditures (CapEx). A comparative analysis is conducted using criteria such as performance metrics, deployment feasibility, scalability, and cost-effectiveness.

2.2. Scenario/Situation Needs Assessment

The second phase focuses on assessing community needs through demographic and geographic data collection, including telecommunication technology, population density, urban versus rural distribution, rural community needs, educational attainment, and existing infrastructure. Data collection methods rely on socio-economic data.

2.3. Strategic Analysis and Strategy Formulation

The final phase integrates the technology and community data to formulate deployment strategies. Community needs are cross-referenced with technology characteristics to develop strategies combining multiple technologies to optimize coverage, performance, and cost-effectiveness. Scenario analysis assesses different deployment strategies under varying conditions and needs (e.g., voice, video, data, telemedicine, emergency service, densely populated rural communities, technological advancements). This approach aids in developing a Situation-Need-Technology Mix matrix to identify effective, efficient, and economical telecommunication deployment strategies tailored to different communities. Continuous evaluation and adaptation ensure these strategies' relevance and sustainability as community needs and technological landscapes evolve.

3. Telecommunication Technology

3.1. Wireless Communication Technologies

Wireless communication refer to technology that provides communication between at least two points without using a wire. Wireless communication technologies may include:

- **Microwave Transport Radio system:** a Microwave radio system used for traffic backhauling between one point to the other (PTP) or between one point to many other points Point to Multipoint (PMP).
- **Cellular Networks:** Including 2G, 3G, 4G, and 5G technologies that provide mobile connectivity.
- **Fixed Wireless Access(FWA)**
- **Wi-Fi:** Wireless local area networking technology.
- **Satellite Communication:** For remote areas, maritime communication, and broadcast services, satellite phone.
- **Bluetooth:** Short-range wireless technology for connecting personal devices.

3.1.1. Microwave Transport Radio System

Microwave transport radio systems use beams of radio waves within the microwave frequency spectrum (300MHz-300GHz) to facilitate data transmission between two points [17]. Consisting of transmitters, receivers, and antennas, these systems transmit signals via either line-of-sight or non-line-of-sight propagation, serving as integral components in point-to-point communication links, backhaul networks, and microwave relay systems [17],[18],[19].

A Microwave link is made up of transmitters, antennas, and receivers, with signals traveling either in a straight line (line-of-sight) or scattered along the path, often characterized by the *"Rician effect"* or and the *Rayleigh effect* for non-line-of-sight transmissions [19]. The range of signal propagation is influenced by various factors such as antenna size, frequency band, modulation scheme, terrain, atmospheric path loss, transmitter power, and receiver sensitivity [21],

[22]. Additionally, there exist point-to-multipoint radios connecting multiple terminal sites to a central nodal or controller site, frequently utilized for enterprise business solutions and backhauling of 3G traffic, albeit lacking mobility and air interface support. A fundamental formula for calculating the received power level (Pr) in a microwave radio link is expressed as:

$$Pr(dBm)=Pt(dBm)-PL(dB)+Gt(dB)+Gr(dB)$$

where $PL(dB)=32.4 + 20\log_{10}(f_{MHz}) + 20\log_{10}(d_{Km})$, Gt= Transmitter Antenna gain, Gr= Receiver Antenna gain, Pt= transmit power.

The capacity of a microwave link, governed by the Nyquist criterion, is determined by the spectrum channel bandwidth (B) and the modulation scheme bits (M). Frequency bands and spectrum channel bandwidths are regulated, allocated and approved for use by communication regulatory agencies of different countries. Microwave Transport radios typically operates within 2.4GHz, 5GHz, 6GHz, 7GHz, 8GHz, 11GHz, 13GHz, 18GHz, and 23 GHz frequency bands, featuring antennas ranging from 0.3m to 3m in diameter. These radios come in configurations like 1+0, 2+0, 4+0, 1+1, 2+2, 4+4, 8+0, and 8+1 depending on the presence of protection schemes and the level and type of protection implemented. Notably, unlicensed radio frequency spectrum in the 2.4GHz and 5GHz bands, classified as Industrial, Scientific, and Medical (ISM) Bands, are also utilized.

Deploying microwave radio links often requires constructing towers or supporting structures for antennas, and indoor equipment housing. As shown in the above formula, depending on factors such as antenna size/gain, Pathloss, frequency, capacity, line of sight, path profile, and transmitter/receiver sensitivity, a point-to-point microwave radio link can span distances of up to 50 km.

Advantages of Microwave Transport Radio:

- **High data transmission rates**: Suitable for applications requiring fast, reliable communication.
- **Low latency**: Ideal for real-time applications like voice communication and video conferencing.
- **Immunity to electromagnetic interference**: Ensures reliable communication in noisy environments.

Disadvantages Microwave Transport Radio

- **Line-of-sight limitations**: Requires unobstructed paths, which can be challenging in rugged or urban areas.
- **Weather dependency**: Susceptible to atmospheric conditions like rain, fog, and snow.
- **Limited capacity**: Compared to fiber optics, microwave channels have less bandwidth.
- **Vulnerability to interference**: Can experience interference from other wireless devices operating in the same bands.

Table 1 below shows Point-to-Point Microwave Radio Application

Table 1 Point-to-Point Microwave transport Radio Application

S/N	Application	Frequency Band	Primary Characteristics	Examples
1	Telecommunication Traffic Backhauling	6 GHz, 7GHz, 8GHz, 11 GHz, 13GHz, 15GHz, 18 GHz, 23 GHz	High capacity, long distance, high reliability	Connecting cellular base stations to network core carrying Voice, data, video traffic
2	Private Network Connectivity	6 GHz, 18 GHz, 23 GHz	Secure, high bandwidth, reliable	Connecting corporate offices, campus networks carrying Voice, data, video traffic
3	Public Safety and Emergency Services	4.9 GHz	High reliability, robust communication, dedicated spectrum	Police, fire, and emergency medical service communications (voice and Data)

4	Utilities and Energy Sector	6 GHz, 11 GHz, 18 GHz	Long distance, high reliability, critical infrastructure monitoring	Connecting substations, monitoring oil and gas pipelines(Data)
5	Military and Defense	L-band (1-2 GHz), X-band (8-12 GHz)	Secure, long-range, resistant to jamming	Tactical communication, radar links(video and Data)
6	Internet Service Providers (ISP)	2.4GHz, 6 GHz, 11 GHz, 18 GHz	High bandwidth, cost-effective, scalable	Rural broadband access, last-mile connectivity(Data)
7	Financial Sector	18 GHz, 23 GHz	Low latency, high security, critical data transmission	Inter-branch communication, stock exchange data links
8	Transport and Traffic Management	6 GHz, 11 GHz	Reliable, real-time data, critical infrastructure	Intelligent transport systems, traffic monitoring
9	Event and Temporary Links	18 GHz, 23 GHz	Rapid deployment, high bandwidth, flexible	Live event coverage, temporary data links
10	Healthcare Networks	11 GHz, 18 GHz	High reliability, secure, critical communication	Hospital network interconnectivity, remote diagnostics

Microwave Transport Radio System Ease of Deployment:

- **Minimal physical infrastructure**: Requires only antennas and towers, making it easier to deploy compared to wired systems.
- **Expedited setup**: Can leverage existing towers or structures, reducing the need for new construction.
- **Quick establishment**: Suitable for backhaul connections or point-to-point communication links.

Factors Affecting Deployment Efficiency:

- **Line-of-sight requirements**: Essential for reliable communication, necessitating careful planning.
- **Spectrum availability**: Licensing from regulatory authorities can impact timelines and costs.
- **Environmental considerations**: Terrain, vegetation, and weather conditions can affect signal propagation.

3.1.2. Cellular Network (Radio Access Network (RAN)

A Radio Access Network (RAN) is a key component of cellular networks, facilitating communication between mobile devices and the core network. It comprises base Transceiver stations, antennas, and other radio equipment, providing wireless connectivity over a designated area. RAN supports various wireless technologies, such as 1G, GSM, CDMA, LTE, and 5G, catering to the increasing demand for high-speed mobile broadband services[23],[24].

Evolution of RAN Technologies

- **1G**: The first generation, introduced in the 1980s, supported only voice calls and had limited capacity and features.
- **2G**: Emerging in the early 1990s, 2G brought voice calls, text messaging, and basic data services. It remains crucial in regions with limited advanced network infrastructure.
- **3G**: Launched in the early 2000s, 3G provided high data transfer rates (up to 2 Mbps), global roaming, and multimedia support.
- **4G**: The fourth generation offered significantly faster speeds and greater capacity than 3G, transforming mobile communications with reliable and efficient connections.
- **5G**: The latest advancement, 5G offers substantial improvements in speed, capacity, latency, and connectivity, aiming to connect virtually everyone and everything. It supports higher multi-gigabit per second peak data speeds, ultra-low latency, and increased reliability.

Cellular Network Technical Overview

Radio access network (RAN) uses the *Rayleigh effect* for signal propagation, employing scattering, reflection, and diffraction to communicate between user equipment (e.g., mobile phones) and cellular antennas without requiring line-of-sight. According to Telecom trainer, The coverage and capacity of RAN are determined by the frequency of operation, spectrum bandwidth, and technologies like MIMO (Multiple Input Multiple Output)(https://www.telecomtrainer.com/discuss-the-techniques-for-optimizing-the-coverage-and-capacity-trade-off-in-5g-networks/. Last accessed 03/06/2024) and beamforming [26]. It is good to note that while the air interface or Uu or NR interfaces may have or guarantee certain capacity, the eventual throughput depends largely on the backhauling or backbone capacity from the cell cites to the core network. Congestion on this segment of the network can limit the effective throughput of cellular networks.

Advantages Cellular Network (Radio Access Network (RAN):

- **Wide coverage**: RANs provide wireless services across large geographic areas, covering urban, suburban, and rural regions.
- **Mobility support**: Seamless handover between base stations allows continuous connectivity for mobile users.
- **Scalability**: RANs can expand by adding base stations or upgrading infrastructure to meet increasing demand.
- **Flexibility**: Supports multiple wireless technologies (GSM, CDMA, LTE, 5G), ensuring compatibility with various mobile devices.

Disadvantages Cellular Network (Radio Access Network (RAN):

- **Limited spectrum availability**: Congestion in densely populated areas can degrade performance.
- **Interference**: Neighboring cells and other electronic devices can cause interference, affecting signal quality.
- **Infrastructure costs**: High costs of deploying and maintaining RAN infrastructure, especially in rural or remote areas.
- **Spectrum licensing requirements**: Regulatory processes for spectrum licenses can be lengthy and expensive.

Cellular Network Application

Table 2 below shows cellular network application

Table 2 Cellular network System application

Generation	Data	Video	Voice	Coverage
1G	Analog, very low data rates	Not supported	Analog voice, low quality	Limited to urban areas, poor indoor coverage
2G	Digital, up to 64 kbps (GPRS), 144 kbps (EDGE)	Limited support, low quality (MMS)	Digital voice, improved quality (GSM)	Improved coverage, rural areas included
3G	Up to 2 Mbps (WCDMA/HSPA), 14.4 Mbps (HSPA+)	Standard definition video streaming	High-quality digital voice (CDMA2000/UMTS)	Wide area coverage, better indoor coverage
4G	Up to 100 Mbps (LTE), 1 Gbps (LTE-A)	High-definition video streaming	VoIP, HD voice (VoLTE)	Extensive coverage, excellent indoor coverage
5G	Up to 10 Gbps (theoretical), 1 Gbps (practical)	Ultra high-definition, 4K/8K video streaming	Ultra-high-quality voice, low latency (VoNR)	Nationwide coverage, including remote and rural areas, superior indoor coverage

Cellular Network System Ease of Deployment

- **Infrastructure requirements**: Deploying RAN involves installing base stations, antennas, and backhaul connections, which can be complex and time-consuming, especially in urban areas.
- **Challenges in remote areas**: Extensive planning and coordination are needed in rural or remote areas due to limited existing infrastructure and challenging terrain.

Factors Affecting Deployment Efficiency:

- **Site acquisition**: Finding suitable locations for base stations can be difficult due to space constraints and regulatory requirements in urban areas, while rural areas may face issues with land access and power supply.
- **Backhaul connectivity**: Reliable backhaul connections are crucial, requiring collaboration with ISPs or deployment of microwave or fiber optic links.

3.1.3. WiFi

Contrary to the understanding that WiFi, means Wireless Fidelity, the word Wi-fi has no meaning. It is a wireless networking technology that enables devices to connect to the internet or local area networks (LANs) without physical connections. Operating on the IEEE 802.11 standard, WiFi uses radio waves to transmit data between devices and access points[29]. The concept of wireless communication dates back to the late 19th century with the invention of radio. Throughout the 20th century, various wireless technologies, such as radio and television broadcasting, were developed. The Institute of Electrical and Electronics Engineers (IEEE) began developing standards for wireless LANs in the late 1980s. In 1997, the IEEE released the first version of the 802.11 standard, which defined the specifications for wireless networking[27] In 1999, several technology companies formed the Wireless Ethernet Compatibility Alliance (WECA), later renamed the Wi-Fi Alliance, to promote and certify interoperability of wireless networking devices based on the IEEE 802.11 standards.

Wi-Fi technology started gaining popularity in the early 2000s as it became more affordable and widely available. Companies began incorporating Wi-Fi into various devices, including laptops, smartphones, and home networking equipment.

Over the years, the IEEE has released several revisions and extensions to the 802.11 standard to improve speed, security, and other aspects of wireless networking. According to cisco, Some notable revisions include 802.11a, 802.11b, 802.11g, 802.11n, 802.11ac, and 802.11ax (Wi-Fi 6).

Today, Wi-Fi has become ubiquitous, powering billions of devices worldwide and enabling wireless connectivity in homes, businesses, public spaces, and even entire cities.

Its widespread adoption in homes, businesses, and public spaces has made it a cornerstone of modern connectivity, providing high-speed internet access[27], [28].

Advantages WiFi

- **Ease of Deployment**: WiFi networks can be set up easily in various environments, including homes, offices, public spaces, and outdoor areas, using readily available hardware and standardized protocols.
- **Cost-Effective**: WiFi equipment is relatively inexpensive compared to wired infrastructure, making it an affordable option for extending internet access.
- **Compatibility**: WiFi supports a wide range of devices, including smartphones, tablets, laptops, and IoT devices, allowing for seamless connectivity.
- **High Data Rates**: WiFi networks offer high-speed data transmission, enabling bandwidth-intensive applications like video streaming, online gaming, and file sharing.

Disadvantages WiFi

- **Limited Range**: WiFi signals typically cover a few hundred feet indoors and slightly farther outdoors, necessitating multiple access points for extensive coverage.
- **Interference**: Operating in unlicensed frequency bands, WiFi can suffer from interference caused by neighboring networks, electronic devices, and physical obstacles.
- **Security Vulnerabilities**: WiFi networks are prone to security threats such as unauthorized access, eavesdropping, and data breaches, requiring robust encryption and authentication mechanisms.
- **Congestion**: In densely populated areas with many WiFi networks, channel congestion can occur, reducing network performance and reliability

Table 3 below detailed WiFi networks Application

Table 3 WiFi Network application

Wi-Fi Standard	Frequency Band	Data	Voice	Video	Coverage
802.11b	2.4 GHz	Up to 11 Mbps, suitable for basic internet browsing, email	Limited support, basic VoIP	Low-quality video streaming (buffering likely)	Limited range, prone to interference
802.11a	5 GHz	Up to 54 Mbps, better data throughput, less interference	Improved VoIP quality	Standard definition video streaming	Shorter range compared to 2.4 GHz, less interference
802.11g	2.4 GHz	Up to 54 Mbps, compatible with 802.11b, better performance	Reliable VoIP	Standard definition video streaming	Similar range as 802.11b, more interference
802.11n	2.4 GHz, 5 GHz	Up to 600 Mbps, MIMO technology, better range and speed	High-quality VoIP, multiple simultaneous calls	High definition (HD) video streaming	Improved range and coverage, dual-band support
802.11ac	5 GHz	Up to 3.46 Gbps, supports MU-MIMO, higher data rates	Very high-quality VoIP, low latency	Ultra high definition (UHD) 4K video streaming	Good range, better indoor coverage, less interference
802.11ax (Wi-Fi 6)	2.4 GHz, 5 GHz, 6 GHz	Up to 9.6 Gbps, OFDMA, improved efficiency and capacity	Excellent VoIP quality, very low latency, supports many devices	Ultra high definition (UHD) 4K/8K video streaming, multiple streams	Excellent range, better coverage in dense environment

Ease of Deployment WiFI

- **Quick and Cost-Effective**: WiFi networks can be deployed rapidly and affordably in diverse environments, using off-the-shelf hardware and standardized protocols.
- **Scalability**: WiFi networks are easily scalable by adding more access points to meet increasing demand or coverage requirements.

Factors Affecting Deployment Efficiency

- **Coverage Planning**: Conducting site surveys and optimizing access point placement are essential to maximize coverage and minimize signal interference, especially in high-density environments.
- **Spectrum Management**: Effective management of WiFi spectrum utilization and channel allocation is crucial to optimize network performance and avoid interference from neighboring networks.

WiFi remains a versatile and essential technology for providing wireless internet access, despite its limitations in range, interference, security, and congestion. With proper planning and management, WiFi networks can deliver reliable and high-speed connectivity across various settings.

3.1.4. Fixed Wireless Access (FWA)

Fixed Wireless Access (FWA) delivers broadband internet to fixed locations using wireless technologies. It employs point-to-point or point-to-multipoint connections to provide high-speed internet to homes, businesses, and remote areas where traditional wired infrastructure is impractical or costly. According to Ericsson publication, FWA offers an alternative solution for bridging the digital divide and extending connectivity to underserved regions(https://www.ericsson.com/en/fixed-wireless-access). Some FWA technologies are leveraging LTE/5G technologies to deliver fast, mobile connectivity services to rural areas.

Advantages Fixed Wireless Access (FWA)

- **Rapid Deployment**: FWA systems can be quickly deployed in areas without wired infrastructure, providing broadband access to underserved and remote locations.
- **Cost-Effective**: FWA eliminates the need for expensive trenching and fiber optic cable installation, reducing deployment costs and accelerating time to market.
- **Flexibility**: FWA systems can be easily reconfigured and relocated to adapt to changing demands or geographical constraints.
- **Broad Coverage**: FWA systems can cover large geographic areas with point-to-point or point-to-multipoint connections, extending connectivity to rural and sparsely populated regions.

Disadvantages Fixed Wireless Access (FWA)

- **Line-of-Sight Requirements**: FWA systems require an unobstructed line-of-sight between transmitter and receiver, limiting coverage in areas with obstructed terrain or dense foliage.
- **Spectrum Licensing**: FWA operators must obtain licenses from regulatory authorities to use specific frequency bands, which involves regulatory compliance and licensing fees.
- **Interference**: FWA systems operating in unlicensed frequency bands may experience interference from other wireless devices, affecting network performance and reliability.
- **Weather Dependence**: FWA systems can be affected by adverse weather conditions such as rain, snow, and atmospheric disturbances, leading to signal attenuation and degradation.

Table4 below shows Application of characteristics of Fixed Wireless Access (FWA)

Table 4 Fixed Wireless Access Network application

Aspect	**Voice**	**Data**	**Video**	**Coverage**
Application	VoIP (Voice over IP), SIP (Session Initiation Protocol)	Broadband Internet Access, IoT Connectivity	Streaming Services, Video Conferencing	Fixed Wireless Access (FWA), Point-to-Point, Point-to-Multipoint
Bandwidth Requirements	Low to Medium (up to 64 kbps per call)	Medium to High (varies by application)	High (1-25 Mbps for SD, 5-100+ Mbps for HD/UHD)	Varies by technology and environment (urban, suburban, rural)
Latency Sensitivity	High (≤ 150 ms round trip)	Medium to High (depends on application)	High (≤ 150 ms for interactive applications)	Low latency required for real-time applications
Quality of Service (QoS)	Critical (jitter, packet loss impact)	Important (varies by application type)	Critical (buffering, latency impact)	Requires strong QoS mechanisms to manage varied traffic types
Technology Used	LTE/5G, Wi-Fi, DECT	LTE/5G, Wi-Fi, Microwave, Millimeter Wave	LTE/5G, Wi-Fi, Satellite, Fiber Backhaul	Depends on the specific deployment, using licensed or unlicensed spectrum
Deployment Scenarios	Residential, Small Business, Remote Locations	Residential, Small to Large Businesses, Remote Sites	Residential, Enterprises, Remote Offices	Urban, Suburban, Rural, Remote Areas
Interference Management	Essential (to avoid call drops, poor quality)	Important (can affect throughput, reliability)	Critical (to avoid buffering, quality degradation)	Line-of-sight (LOS) or non-line-of-sight (NLOS) environments impact performance
Scalability	Scalable with QoS and sufficient bandwidth provisioning	Highly scalable with sufficient backhaul	Scalable with adaptive bitrate streaming	Scalability depends on spectrum availability and technology choice

Fixed Wireless Access Node Ease of Deployment

- **Rapid and Cost-Effective**: FWA systems offer rapid deployment and cost-effective broadband access for residential, commercial, and rural applications, leveraging wireless technologies such as microwave, LTE, and 5G.
- **Scalability**: FWA networks can be easily expanded by adding additional base stations or subscriber units to meet growing demand or coverage requirements.

Factors Affecting Deployment Efficiency

- **Spectrum Availability**: Obtaining spectrum licenses from regulatory authorities is critical for FWA deployment, requiring coordination and compliance with spectrum regulations and licensing procedures.
- **Backhaul Connectivity**: Ensuring reliable backhaul connections for FWA infrastructure is essential. This may involve deploying microwave links, fiber optics, or satellite connections depending on geographical and operational considerations.

FWA remains a viable solution for extending high-speed internet access to areas where traditional wired infrastructure is either impractical or too expensive to deploy. According to Heredia, R., "The Essential Guide to Fixed Wireless: A Viable Wireless Broadband Solution for High-Speed Business Internet", with proper planning and management, FWA can effectively bridge the connectivity gap, especially in remote and rural regions(: https://www.zipitwireless.com/fixed-wireless-broadband-solution-for-business-internet#:~ =Fixed%20wireless%20access%20%28FWA%29%20is%20a%20cost-effective%20solution,faster%20return%20on%20investment%20compared%20to%20fiber%20infrastructure Last access 03/06/2024).

3.1.5. Fiber Optics

Fiber optic communication relies on transmitting data through optical fibers made of glass or plastic, using light signals to carry information over long distances. This technology offers high bandwidth, low latency, and immunity to electromagnetic interference, making it ideal for long-haul communication networks, metropolitan area networks (MANs), and local area networks (LANs). Fiber optic cables consist of a core surrounded by a cladding layer, with signals transmitted through total internal reflection.

Capacity of a fiber optics depends largely on the multiplexing scheme, modulation, technology capability of the terminating optical equipment. Various modulation scheme like QPSK, 16QAM, OFDM and multiplexing scheme like WDM, DWDM and TDM deliver different capacity even over the same optical fiber cable.

Advantages Fiber Optics Cable

- **High Bandwidth**: Fiber optic cables can transmit significantly more data than traditional copper cables, making them ideal for high-speed internet, multimedia streaming, and large-scale data transmission.
- **Low Attenuation**: These cables experience minimal signal loss over long distances, allowing data to travel further without the need for signal regeneration.
- **Immunity to Electromagnetic Interference (EMI)**: Unlike copper cables, fiber optic cables are unaffected by electromagnetic interference, ensuring reliable performance in environments with high electrical noise.
- **Security**: Fiber optic cables are difficult to tap without detection, providing a higher level of security for transmitting sensitive data.
- **Lightweight and Small Size**: Fiber optic cables are thinner and lighter than copper cables, which simplifies installation and maintenance.
- **Longevity**: Fiber optic cables generally have a longer lifespan than copper cables and require less maintenance, leading to lower long-term costs.

Disadvantages Fiber Optics Cable

- **Initial Cost**: Establishing fiber optic infrastructure can be expensive, including the cost of specialized equipment and skilled labor for installation.
- **Fragility**: Fiber optic cables are more delicate than copper cables and can be easily damaged if not handled carefully, potentially causing signal loss or interruptions.
- **Limited Flexibility**: These cables are less flexible than copper ones and may not be suitable for applications requiring frequent bending or movement.

- **Dependency on Light Source**: Fiber optic communication relies on light signals, which can be disrupted by factors such as bends in the cable, contaminants, or issues with the light source.
- **Complexity of Installation**: Installing fiber optic cables requires specialized knowledge and equipment, making the process more complex and time-consuming compared to other transmission mediums.
- **Limited Availability in Rural Areas**: Fiber optic infrastructure may not be as readily available in rural or remote areas, limiting its accessibility compared to traditional copper-based systems.

Application of Fiber optics and optical Network are stated in the Table 5 below.

Table 5 Fiber optic Network Application

Aspect	**AI**	**Data**	**Voice**	**Video**
Application	AI Training, Inference, Data Transfer	High-Speed Data Transfer, Cloud Computing	VoIP (Voice over IP), SIP (Session Initiation Protocol)	Video Conferencing, Streaming Services
Bandwidth Requirements	High (depends on model complexity)	High (depends on data volume, application)	Low to Medium (up to 64 kbps per call)	High (1-25 Mbps for SD, 5-100+ Mbps for HD/UHD)
Latency Sensitivity	Variable (depends on application)	Variable (depends on application)	Low (typically ≤ 150 ms round trip)	High (≤ 150 ms for interactive applications)
Security	Important (data privacy, model protection)	Critical (data encryption, secure transmission)	Important (secure signaling, authentication)	Critical (content protection, DRM)
Reliability	Important (data integrity, model accuracy)	Critical (data integrity, uptime)	Critical (call quality, reliability)	Critical (stream continuity, uptime)
Technology Used	Fiber Optic Cables, Data Centers	Fiber Optic Cables, Cloud Networks	Fiber Optic Cables, VoIP Gateways	Fiber Optic Cables, Video Streaming Platforms
Deployment Scenarios	Data Centers, Edge Computing	Data Centers, Enterprise Networks	Residential, Business Offices	Residential, Business Offices
Interference Immunity	Immune to electromagnetic interference	Immune to electromagnetic interference	Immune to electromagnetic interference	Immune to electromagnetic interference
Scalability	Highly Scalable (distributed processing, parallelism)	Highly Scalable (cloud resources, network capacity)	Scalable with QoS and bandwidth provisioning	Scalable with adaptive bitrate streaming

Fiber Optics cable Ease of Deployment

- **Planning and Installation**: Fiber optic networks require meticulous planning and installation due to the delicate nature of the cables.
- **Laying Cables**: Deployment involves laying fiber optic cables underground or on utility poles, which can be time-consuming and costly.
- **Advancements in Cable Design**: Developments such as flexible and armored cables have made deployment more manageable in challenging environments.

Factors Affecting Deployment Efficiency of Fiber Optics Cable

- **Right-of-Way Access**: Obtaining rights-of-way for laying fiber optic cables can be a significant challenge, especially in urban areas with congested infrastructure and regulatory restrictions.

- **Construction Permits**: Securing permits for trenching, excavation, and road closures is essential for fiber optic deployment and may involve lengthy approval processes.
- **Civil Works**: Excavation, trenching, and cable installation require coordination with construction crews and utility companies, adding complexity and cost to deployment efforts.

Fiber optics represent a robust and efficient solution for modern communication needs, offering unparalleled bandwidth and reliability. Despite the challenges associated with their deployment, the long-term benefits make fiber optics a cornerstone of future communication infrastructures.

3.1.6. Satellite Communication Systems

Satellite communication systems utilize orbiting satellites to relay signals between ground stations, enabling global connectivity over vast distances. These systems offer ubiquitous coverage and are particularly valuable in remote and underserved areas where terrestrial infrastructure is limited or non-existent. Satellite communication supports a wide range of applications, including broadcasting, telephony, internet access, and remote sensing [34], [36], [37]. Notably, three geosynchronous satellites can provide global coverage.

Orbital Satellites Characteristics

Satellite systems operate across different orbits, each offering unique advantages and challenges:

- **Low Earth Orbit (LEO)**: Altitudes ranging from 160 to 2,000 kilometers, suitable for low-latency, high-data-rate applications.
- **Medium Earth Orbit (MEO)**: Altitudes between 2,000 and 35,786 kilometers, offering intermediate latency and coverage suitable for navigation and communication networks.
- **Geostationary Earth Orbit (GEO)**: Altitude approximately 35,786 kilometers, providing continuous coverage over specific regions, ideal for broadcasting and communication services.

There are different method of exploring satellite for telecommunication services. The use of Very Small Aperture Terminal (VSAT) and Earth station as ground communication terminals pointing to the satellite are the commonest ways of using satellite as telecommunication medium. VSAT refers to satellite ground station antenna with size range of 0.75-2.4m. According to orbitHub “VSAT Satellite Technology: Everything You Need To Know “ a satellite ground station’ antenna bigger than 2.4m diameter is refer to as Earth Station(https://orbitshub.com/vsat-satellite-technology-everything-you-need-to-know/. (last accessed: 03/06/2024),[54]. Satellite communications system different access scheme like Time Division Multiple Access (TDMA), Single Channel Per Carrier(SCPC), Permanently Assigned multiple Access (PAMA) and Demand Assigned Multiple Access(DAMA)[55]. There are other scheme like Carrier-in-Carrier(C-in-C) that allows for capacity doubling. Satellite communication topology can take different forms including:

- Remote Site -to-Hub- Head Quarter: This type of connection results in high latency because the round trip time is doubled.
- Remote Site-to-Hub-Fiber cable-to-HQ: Instead of installing another earth station at the HQ, fiber cable is used to backhaul the traffic to the HQ
- Remote Site-to-HQ: in this scenario, the satellite system hub is situated in HQ. it is commonly used when the satellite system is private and the Hub is not shared with other customers.
- Remote Site-to-Hub-Microwave Radio-to-HQ: Microwave radio is used to backhaul the remote site traffic from the Hub site to the HQ reducing the round trip time (RTT).
- Remote Site-to-Hub-internet: When the essence of the VSAT is for internet connectivity, this topology is employed. A similar topology is used in Receive only (RO) as it applies to Internet TVs.
- UE-Satellite-Hub-Cellular Core Networks is the topology in the satellite phone communication scenario.

A typical VSAT or earth station will contain at least one or more of the following components: LNA- Low Noise Amplifier, LNB-Low Noise Block, SSPA- Solid State Power Amplifier, HPA- High power Amplifier, BUC- Block Up converter, Modem-MODulator/DEModulator, Satellite step auto-tracker.

Advantages of Satellite Communication

- **Global Coverage**: Enables communication across vast geographical areas, including remote and inaccessible regions.
- **Reliability**: Less susceptible to natural disasters and physical disruptions, offering high reliability.

- **Scalability**: Can accommodate a large number of users simultaneously, suitable for broadcasting and telecommunication on a massive scale.
- **High Bandwidth**: Supports applications such as HD video streaming, broadband internet access, and data-intensive communications.
- **Mobility**: Serves mobile users, providing continuous connectivity while in motion.
- **Quick Deployment**: Can be deployed relatively quickly, making them ideal for emergency communication and disaster recovery scenarios.

Disadvantages of Satellite Communication

- **Latency**: Signals travel long distances, resulting in delays, which can affect real-time applications.
- **Cost**: Building, launching, and maintaining satellites is expensive. However, there are satellite service providers that lease bandwidth to users. Hence, there is no need to invest in launching a satellite for the sole purpose of connecting a community.
- **Weather Interference**: Adverse weather conditions can disrupt satellite signals.
- **Limited Bandwidth**: Faces limitations in total available bandwidth, leading to congestion during peak usage periods.
- **Security Concerns**: Vulnerable to interception and unauthorized access.
- **Orbital Debris and Collision Risk**: Increasing space debris raises collision risks, potentially damaging operational satellites.

Table 6 below detailed Characteristics and Application of different types of Satellite orbits and VSAT

Table 6 Characteristics and Application of different Orbital Satellites

Parameter	**LEO (Low Earth Orbit)**	**MEO (Medium Earth Orbit)**	**GEO (Geostationary Earth Orbit)**
Altitude	500 - 2,000 km	2,000 - 35,786 km	35,786 km
Orbital Period	90 - 120 minutes	2 - 12 hours	24 hours
Coverage Area	Small (dynamic coverage)	Moderate	Large (fixed coverage, ~1/3 of Earth)
Latency	Low (20 - 30 ms)	Medium (50 - 150 ms)	High (250 - 600 ms)
Signal Strength	Strong, less power required	Moderate	Weaker, more power required
Satellite Life Span	5 - 8 years	10 - 15 years	15 - 20 years
Constellation Size	Large (tens to hundreds)	Moderate	Small (usually 1 - 3 per global service)
Launch Cost	Lower per satellite	Moderate	High per satellite
Tracking Requirements	High (requires frequent handovers)	Moderate	Low (stationary relative to Earth)
Primary Applications	LEO (Low Earth Orbit)	MEO (Medium Earth Orbit)	GEO (Geostationary Earth Orbit)
Voice Communication	Low-latency voice services, satellite phones	Mobile voice services	Fixed satellite services, VoIP
Video Communication	Real-time video conferencing, streaming	High-definition broadcasting	Direct-to-home TV, broadcast services
Data Communication	Internet of Things (IoT), remote sensing, broadband	GPS, data relay, broadband	Internet backbones, weather monitoring
Advantages	Low latency, global coverage, lower launch cost	Balance of coverage and latency, useful for GNSS	Broad coverage, no tracking needed, long lifespan

Disadvantages	Short lifespan, complex tracking, frequent handovers	Higher latency than LEO, fewer satellites needed but higher launch cost	High latency, high launch and maintenance cost

Satellite/VSAT systems Ease of Deployment

Satellite communication systems provide critical connectivity solutions, especially in remote areas:

- **Rapid Deployment**: Offer near-instantaneous global coverage once in orbit.
- **Infrastructure Independence**: Do not require extensive ground infrastructure.

Factors Affecting Deployment Efficiency of Satellite/VSAT systems

Several factors influence deployment efficiency:

- **Regulatory Compliance**: Obtaining spectrum licenses and coordinating orbital slots.
- **Launch and Technical Infrastructure**: Choice of launch vehicle and satellite manufacturing.
- **Network Management**: Establishment of ground stations and operational resilience.
- **Backhaul Connectivity**: Integration with terrestrial networks for reliable connectivity.

In conclusion, satellite communication systems offer rapid and cost-effective global connectivity solutions, especially beneficial for remote and underserved areas [37]. While deployment is facilitated by minimal ground infrastructure, addressing regulatory compliance, technical infrastructure, and backhaul connectivity is essential for successful deployment [38].

4. Technology Scalability and Adaptability to Different Environments:

Scalability and adaptability are essential considerations when selecting and deploying telecommunication technology and infrastructure, particularly in dynamic or evolving environments. Scalability refers to the ability of a communication technology to accommodate increasing demand or changing requirements by expanding or upgrading the network infrastructure [46], [47], [48]. Adaptability refers to the ability of a communication mode to function effectively in different environmental conditions, such as urban, suburban, rural, or remote areas.

Some telecommunication technologies, such as fiber optics and wireline networks, offer inherent scalability, allowing for easy expansion and customization to meet evolving demands. However, these modes may be less suitable for deployment in remote or rural areas due to infrastructure limitations, terrain difficulty and high deployment costs [44], [46].

On the other hand, wireless technologies like microwave transport radio, cellular systems, WiFi, satellite communication (VSAT) and FWA offer greater flexibility and adaptability to different environments, enabling rapid deployment and extending connectivity to underserved regions [40] These deployment modes can be scaled up or down as needed, making them suitable for diverse deployment scenarios ranging from urban centers to remote villages.

Also, scalability and adaptability considerations should also consider factors such as spectrum availability, regulatory constraints, network management complexity, and long-term sustainability. A balanced approach is necessary to ensure that the chosen communication mode can meet current needs while it's also scalable and adaptable to future requirements and environmental [39].

4.1. Comparative Analysis of Telecommunication Technologies

Performing a comparative analysis of performance, reliability, scalability and cost across different telecommunication technologies requires considering various factors such as data throughput, latency, coverage area, signal quality, deployment costs, and operational expenses. Each communication mode has its strengths and weaknesses in these aspects, and the optimal choice depends on the specific requirements and constraints of the deployment scenario. Table7 below presents the comparative analysis of different telecommunication technologies.

Table 7 Comparative analysis of various telecommunication technologies

Technology	Performance	Reliability	Cost	Scalability
Microwave Transport Radio	High-speed data transfer, suitable for long distances	Moderate (weather-dependent)	Moderate (equipment and installation)	High (easily scalable with additional links)
Cellular Radio				
1G	Analog voice, poor data performance	Low (prone to interference and dropouts)	Low (outdated technology)	Low (limited to voice communication)
2G	Digital voice, SMS, limited data (GPRS, EDGE)	Moderate (better than 1G)	Low to moderate	Moderate (limited data capacity)
3G	Enhanced data speeds, video calls, mobile internet	Moderate to high	Moderate	High (significant improvement over 2G)
4G	High-speed internet, HD video streaming, VoIP	High	High (infrastructure cost)	High (supports numerous applications and users)
5G	Ultra-high-speed internet, low latency, IoT, real-time applications	High	Very high (new infrastructure)	Very high (massive device connectivity, IoT, smart cities)
Wi-Fi	High-speed local data transfer, depends on standard (802.11n/ac/ax)	Moderate to high (depends on network setup)	Low to moderate (home, enterprise)	High (scalable within local areas, enterprise environments)
Fixed Wireless Access (FWA)	High-speed internet, depends on technology (4G/5G based)	High	Moderate (equipment and setup)	High (scalable for rural and underserved areas)
Fiber Optics	Extremely high bandwidth, low latency, long distances	Very high (immune to electromagnetic interference)	High (installation and maintenance)	Very high (scalable with future-proof technology)
Copper Wire	Limited bandwidth, high attenuation over long distances (e.g., DSL)	Moderate (subject to interference)	Low to moderate (existing infrastructure)	Low to moderate (limited by physical properties)
VSAT/Earth Station	Moderate bandwidth, high latency, suitable for remote areas where other connections are not feasible	High (dependent on satellite reliability and weather conditions)	Moderate to high (leasing bandwidth and equipment costs)	High (global reach, limited by available sate

5. Strategies for Building a Connected Nation

Building a connected nation requires a comprehensive approach that integrates **Situation-Need-Technology Mix Matrix,** fosters public-private partnerships, and establishes supportive policy recommendations and regulatory frameworks. These strategies aim to promote inclusive growth, bridge the digital divide, and ensure equitable access to telecommunications services across the country.

5.1. Integrated Approach to Technology selection and deployment:

An integrated approach to technology adoption involves leveraging a diverse range of telecommunication technologies to extend connectivity to urban, suburban, rural, and remote areas. It takes into account the inherent characteristics, limitations, strength and application of various technologies discussed earlier. This approach also consider the feasibility of combining two or more technologies to meet the needs of a community of people. Example of this include:

- **Fiber Optic Backbone:** Deploying a robust fiber optic backbone network forms the foundation for high-speed broadband connectivity, enabling reliable and scalable communication infrastructure across the country [49]. Fiber optic networks provide the backbone or backhauling bandwidth capacity necessary to support growing data demands and emerging technologies, such as 5G, IoT, and cloud computing[50].
- **Wireless Technologies:** Wireless communication modes, including mobile networks, fixed wireless access (FWA), and satellite systems, complement fiber optic infrastructure by extending connectivity to areas where wired deployment is challenging or economically infeasible. Mobile networks, in particular, provide ubiquitous coverage and support mobility, enabling seamless connectivity for urban and rural users alike.
- **Emerging Technologies:** Embracing emerging technologies, such as 5G, edge computing, and artificial intelligence (AI), enhances the efficiency, reliability, and intelligence of telecommunication networks. 5G networks offer ultra-low latency, high reliability, and massive connectivity, enabling innovative applications such as autonomous vehicles, smart cities, and industrial automation. However, it has to ride on robust optical backbone network to deliver on the throughput to the core network.

5.2. Situation-Need-Technology Mix Matrix(SNTMM) for Telecommunication Technologies Deployment

In today's diverse telecommunication landscape, selecting the optimal technology to deliver connectivity solutions depends on various factors such as geographical location, population density, infrastructure availability, fund and specific communication needs. The following matrix provides a comparative analysis of different scenarios, identifying the specific needs and recommending suitable cost effective telecommunication technologies to meet those needs. This comprehensive matrix addresses performance, reliability, and cost considerations for each situation, ensuring that the most effective and efficient communication solutions are implemented.

A developed Situation-Need-Technology Mix Matrix(SNTMM) is shown in table8 below

Table 8 Situation-Need-Technology mix Matrix

S/N	Situation	Need	Technology	Description
1	Densely populated but isolated community	Voice & Data service	Satellite + RAN	Deploy RAN in the community and use Satellite to backhaul the traffic to BSC site.
2	Sparsely populated but isolated community	Data	Satellite + WiFi	Use Satellite to provide connectivity and distribute it via WiFi within the area.
3	Isolated small community relatively close to a cell site	Voice & Data	Fixed Wireless Access (FWA)	Extend cell site connectivity using FWA to cover the community.
4	Densely populated urban area	Voice, High speed data & Video streaming	Fiber (Backhauling) + RAN (4G/5G)	Utilize Fiber for backhaul and deploy RAN (4G/5G) for local distribution.
5	Closely connected communities	Voice, Data, and Video	RAN (4G/5G) + Microwave Radio	Use RAN for local coverage and Microwave Radio to link up the sites.
6	Isolated community with difficult terrain	Data (Broadband penetration)	Satellite + FWA	Provide broadband via Satellite and distribute locally using FWA.
7	Rural area with occasional natural disasters	Emergency communication	Mobile Satellite Services (MSS)	MSS can provide reliable emergency communication during natural disasters when terrestrial networks may be down.

8	Coastal community with high tourist influx during certain seasons	High-speed internet and mobile connectivity	RAN (4G/5G) + Temporary Cell Sites	Deploy temporary cell sites during peak seasons and use 4G/5G RAN to handle the increased demand.
9	Industrial area with extensive automation	Low latency, reliable connectivity	Private LTE/5G Network	Implement a private LTE/5G network to ensure low latency and reliable connectivity for automated processes.
10	Developing region with limited infrastructure	Basic communication services	GSM + Solar-powered BTS	Use GSM technology with solar-powered base transceiver stations (BTS) to provide basic communication services where power supply is unreliable.
11	Mountainous area with scattered villages	Voice and basic data	Low band Microwave Radio + Satellite	Use Low-band Microwave radio for local communication between villages and satellite for long-distance communication.
12	Suburban area with growing population	Scalable high-speed internet	Fiber to the Home (FTTH)	Deploy Fiber to the Home (FTTH) to provide scalable high-speed internet as the population grows.
13	Urban business district	Ultra-reliable low latency communication (URLLC)	5G mmWave	Utilize 5G mmWave technology to provide ultra-reliable and low latency communication needed for business applications.
14	Agricultural region with smart farming initiatives	IoT Connectivity	LoRaWAN + Cellular IoT (Long-Range Wide Area Network)	Deploy LoRaWAN for wide-area low-power IoT connectivity and cellular IoT for higher bandwidth requirements.
15	Isolated island with limited power infrastructure	Renewable energy-powered communication	Hybrid Solar-Wind + Satellite	Use a hybrid solar-wind power system to support satellite communication infrastructure, ensuring sustainable connectivity.
16	Historic city center with restrictions on infrastructure development	High-speed mobile connectivity	Small Cells + Fiber Backhaul	Implement small cells with fiber backhaul to provide high-speed mobile connectivity while adhering to infrastructure restrictions.
17	Commuter routes (highways and railways)	Continuous mobile connectivity	Distributed Antenna System (DAS)	Use DAS along commuter routes to ensure continuous and reliable mobile connectivity for travelers.
18	Remote mining site	High-capacity data transfer	Microwave Link + WiFi	Establish a microwave link for high-capacity data transfer to a nearby data centre and use WiFi for on-site connectivity.
19	National park with conservation efforts	Low-impact communication	Satellite + Environmental Sensors	Deploy satellite communication for connectivity and environmental sensors for monitoring without significant infrastructure impact.

20	High-altitude research station	Reliable data transmission	Satellite + High-frequency Radio	Use satellite for reliable data transmission to and from the research station, supplemented by high-frequency radio for local communication.

5.3. Public-Private Partnerships and Collaboration:

Public-private partnerships (PPPs) and collaboration between government agencies, telecommunications providers, industry stakeholders, and community organizations are essential for accelerating telecommunication infrastructure development and expanding connectivity nationwide.

- **Infrastructure Investment:** Governments can incentivize private sector investment in telecommunication infrastructure through tax incentives, subsidies, grants, and regulatory support. Public financing mechanisms, such as infrastructure bonds and public-private investment funds, can mobilize capital for critical infrastructure projects and promote private sector participation.
- **Resource Sharing:** Collaboration among telecommunications providers for infrastructure sharing, spectrum sharing, and network interoperability enhances resource efficiency and accelerates deployment. Infrastructure sharing agreements, such as tower sharing and fiber sharing arrangements, reduce duplication of investment and promote cost-effective network expansion.
- **Community Engagement:** Engaging local communities, stakeholders, and end-users in the planning, implementation, and management of telecommunication projects fosters grassroots support and ensures that connectivity initiatives address local needs and priorities. Community-driven initiatives, such as community broadband networks and digital literacy programs, empower citizens to take ownership of their digital future and participate in the digital economy.

5.4. Policy Recommendations and Regulatory Frameworks:

Enacting supportive policy recommendations and regulatory frameworks is essential for creating an enabling environment for telecommunication infrastructure development, fostering competition, and safeguarding consumer interests.

- **Spectrum Management:** Governments should adopt transparent, predictable, and technology-neutral spectrum allocation policies to promote efficient spectrum use and facilitate innovation in wireless communication technologies. Spectrum auctions, licensing regimes, and spectrum sharing arrangements ensure equitable access to radio frequency spectrum while maximizing its economic and social value.
- **Regulatory Reform:** Streamlining regulatory processes, reducing bureaucratic barriers, and harmonizing regulatory requirements across jurisdictions promote investment certainty and reduce regulatory compliance costs for telecommunications providers. Regulatory reforms should foster competition, encourage innovation, and protect consumer rights through effective market oversight and enforcement.
- **Universal Service Obligation:** Implementing universal service obligations (USOs) ensures that all citizens have access to basic telecommunication services, regardless of their geographical location or socio-economic status. USOs may include minimum service quality standards, affordability measures, and targeted subsidies to bridge the digital divide and promote digital inclusion.

In conclusion, building a connected nation requires a multi-faceted approach that integrates combination of technologies, fosters public-private partnerships, and establishes supportive policy recommendations and regulatory frameworks. Through a cost-effective technology derived from SNTM matrix, collaboration, and inclusive growth strategies, countries can harness the transformative power of telecommunications to drive economic development, empower communities, and build a prosperous digital future for all citizens.

6. Conclusion

6.1. Summary of Findings:

In this scholarly exploration of telecommunication technology ecosystems I have examined various communication technologies, including wireless, and wireline, and their applications in the Urban, remote and rural areas. I discussed the advantages and disadvantages of each communication mode, comparative analysis of performance, reliability, and cost, scalability, adaptability to different environments, and regulatory considerations.

The investigation highlighted the critical role of telecommunication technologies in facilitating digital connectivity for rural communities, and supporting data, voice and video. A Situation-Need-Technology Mix Matrix(SNTMM), which combined two or more technologies to deliver connectivity depending on the scenario and the need was developed. I explored strategies for building a connected nation, including an integrated approach to technology adoption, public-private partnerships, and supportive policy recommendations and regulatory frameworks.

6.2. Implications for Policy and Practice:

The findings of this study have several implications for policy makers, telecommunications providers, industry stakeholders, and community organizations.

- There are technology solutions (Combination of two or more transmission technologies) that will deliver connectivity to rural communities at a relatively moderate cost.
- Strategically tailored technology solution and selection will reduce the cost burden of building a connected nation.
- Policy makers should prioritize investment in telecommunication infrastructure, promote public-private partnerships, and enact supportive regulatory frameworks to accelerate connectivity and bridge the digital divide.
- Telecommunications providers should leverage a diverse range of technologies, collaborate with government agencies and community organizations, and invest in innovation to expand access to telecommunication services and enhance service quality.
- Industry stakeholders should engage in infrastructure sharing, spectrum management, and capacity building initiatives to optimize resource utilization and promote sustainable growth in the telecommunication sector.
- Community organizations should advocate for digital inclusion, promote digital literacy, and empower marginalized communities to participate in the digital economy.

6.3 Future Directions for Research and Development:

Future research and development efforts in the field of telecommunication technology ecosystems should focus on topic that carry out:

- Investigation of the effect of telecommunication services on Rural-urban migration.
- Cost effectiveness of Private LTE/5G for rural connectivity.

In conclusion, the findings of this study underscore the importance tailored telecommunication technologies in building a connected nation and advancing socio-economic development. By embracing innovation, collaboration, and inclusive growth strategies, countries can harness the transformative power of telecommunications to create a more prosperous and equitable society for all citizens.

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