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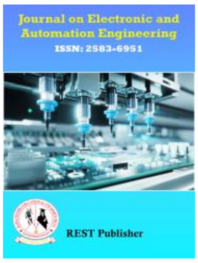

Enhancing Connectivity and Communication in Underserved Rural and Remote Areas - An EDAS-Based Invest

*** [1]Deepak Das, [1]Somesh Nagalla, [2]Nihari Paladugu**
[1]IEEE Member, Texas, USA,
[2]IEEE Member, Ohio, USA
*Corresponding author: ***dasdeepak2288@aol.com***

Abstract: *The increasing dependence of contemporary society on uninterrupted connectivity and communication emphasizes the importance of tackling the digital disparity present in rural and remote areas with limited access. The research carries immense importance in the field of telecommunications and the drive for digital equity. In a time when connectivity plays a pivotal role in advancing economies, societies, and education, the stark digital divide between urban centers and underserved rural zones holds significant and far-reaching consequences. Given that remote and rural locales frequently grapple with infrastructural constraints, the adoption of virtualized networks presents an opportunity to transcend conventional limitations and extend the advantages of digital access to these communities. Through leveraging the capabilities of the EDAS methodology, this research endeavors to uncover inventive approaches to enhance connectivity and communication. Alternate and Evaluation Parameters taken as This research embarks on an exhaustive examination of a variety of connectivity options, encompassing Traditional Cellular Network Expansion, Satellite Internet, Community Mesh Networks, NFV-based Rural Edge Servers, and Hybrid Fiber-Wireless Networks. The overarching objective is to effectively respond to the pressing requirement for improved connectivity. Employing the EDAS technique, this study endeavors to evaluate these distinct strategies using a comprehensive set of evaluation metrics. These metrics include measures such as Connectivity (%), Data Speed (Mbps), Latency (ms), Initial Cost ($), and Operational Cost ($).The Aggregated Score index (ASi) ranks the connectivity expansion alternatives as follows: Community Mesh Networks lead with an ASi of 0.7645, securing the top rank (1). Following closely are NFV-based Rural Edge Servers with an ASi of 0.6498 and the second rank, Hybrid Fiber-Wireless Networks with an ASi of 0.4207 and the third rank, Satellite Internet with an ASi of 0.2963 and the fourth rank, and Traditional Cellular Network Expansion with an ASi of 0.2671, holding the fifth rank. The ranking reflects the overall performance of each alternative based on aggregated scores.*

1. INTRODUCTION

Rural and remote areas often suffer from a lack of connectivity and accessible communication networks compared to more populated urban regions. This digital divide limits economic opportunities, access to essential services like healthcare and education, and overall quality of life for rural residents. Bridging this connectivity gap is crucial for supporting rural community development and reducing inequality [1,2].

The lack of connectivity in rural areas isolates residents from vital resources and opportunities. A 10-percentage point increase in broadband penetration could raise per capita GDP by 1.4% in developing countries. However, rural regions often lag behind by 20-30% in internet access rates. For example, fixed broadband adoption is less than 20% in rural India versus over 60% in cities (IAMAI, 2019) [3,4].

Less than 60% of rural households globally have access to broadband internet compared to over 80% coverage in urban areas. Slower, older copper wire infrastructure predominates in rural zones, offering speeds below 25Mbps which is insufficient for many modern applications. Rural users also face challenges from lack of network redundancy, geographic and technical barriers like mountains and forests, higher costs due to remote installations, and depopulation shrinking customer bases. These connectivity limitations restrict rural communities [5].

Bridging the rural digital divide facilitates socioeconomic development. Rural e-commerce exposes small businesses to more customers. Distance learning can provide quality education regardless of geography. Telemedicine empowers healthcare diagnosis and administration. E-governance improves access to public services and entitlements. A study across Indian villages found internet availability raised worker wages by 7% and reduced poverty by 17%. Connectivity is an enabler for digital transformation across all sectors [6].

Despite covering over 80% of land area worldwide, rural regions are home to less than 50% of the global population. However, enhancing rural access delivers major social and economic benefits. Rural businesses can expand markets with digital capabilities. Telemedicine improves healthcare outcomes by connecting patients to distant specialists. Online education provides learning opportunities without transportation barriers. E-governance improves public services and transparency. Better networks allow increased remote work, potentially slowing urbanization. Connectivity is essential for sustainable development across communities [7].

The Indian government funded EDAS pilots for rural villages under its BharatNet project starting around 2012. Network nodes were adapted to local power and climatic conditions, often solar powered with fanless heat sinks. Nodes provided village information services, telemedicine, education resources and e-governance applications. Early deployments faced challenges like intermittent power, limited fiber backhaul and coordination issues. However, success factors included active local participation, capacity building, and open APIs. The BharatNet case study demonstrated EDAS potential while revealing areas for improvement [8].

New technologies and business models are needed for affordable rural access. Legacy solutions like fixed broadband have proven cost-prohibitive in sparse populations. Innovative options such as community networks, Wi-Fi mesh topologies, and universal service funds are gaining interest. Optimized architectures can also maximize limited infrastructure. The partitioned structure and distributed capabilities of Evolved Data Access Systems (EDAS) lend well to rural constraints. This investigation analyzes the feasibility of EDAS networks to enhance rural connectivity [9].

The Mesh Enabled Architecture (MEA) model utilizes EDAS principles for rural connectivity in Africa. MEA networks apply smart caching and partition databases to community mesh topologies. These limits backhaul usage while retaining local access to crucial data during outages. MEA platforms have provided local schools with educational materials, supported healthcare workers through decision tools, and enabled micropayment solutions. Costs can be as low as $1000 per village node. The MEA case study showcases EDAS abilities to maximize limited infrastructure through judicious decentralization [10].

While mobile and satellite broadband have expanded rural options, performance and affordability issues remain compared to urban fiber networks. Community-led solutions like mesh networks are emerging as complements. Optimized network architectures can also overcome cost and infrastructure barriers. The distributed, incremental scalability of EDAS makes it well-suited for rural settings if implementation challenges can be addressed [11].

2. MATERIALS METHODS

This study embarks on a thorough investigation of a spectrum of connectivity alternatives, spanning Traditional Cellular Network Expansion, Satellite Internet, Community Mesh Networks, NFV-based Rural Edge Servers, and Hybrid Fiber-Wireless Networks. The central aim is to effectively address the urgent need for enhanced connectivity.

Through the utilization of the EDAS methodology, this research strives to appraise these distinct strategies utilizing a comprehensive suite of evaluation measures. These measures encompass factors such as Connectivity (%), Data Speed (Mbps), Latency (ms), Initial Cost (in $1000), and Operational Cost (in $1000). By subjecting these options to a meticulous evaluation based on these criteria, the study endeavors to unearth insights that will facilitate the identification of the most optimal course of action for augmenting connectivity and communication in rural and secluded areas.

Alternative Approaches:

1. **Expanding Traditional Cellular Networks:** This involves enhancing and expanding conventional cellular networks, widely used for mobile communication. It encompasses adding more cell towers and improving existing infrastructure to offer improved coverage and connectivity.

2. **Satellite Internet Provision:** Satellite internet entails utilizing communication satellites to deliver internet access. It proves particularly beneficial in secluded or rural regions where conventional broadband infrastructure might be absent.
3. **Community Mesh Networks:** Community mesh networks establish a decentralized network structure wherein various devices (often owned by community members) interconnect to form a broader network. This fosters local connectivity without sole dependence on centralized infrastructure.
4. **Rural Edge Servers through NFV:** Network Function Virtualization (NFV) entails virtualizing network services that were historically reliant on dedicated hardware. In the context of rural edge servers, it implies deploying virtualized network services at the outskirts of rural networks to enhance connectivity.
5. **Hybrid Fiber-Wireless Networks:** These networks amalgamate fiber-optic cables (for high-speed, reliable data transmission) with wireless technology (like mobile or Wi-Fi) to craft a versatile and comprehensive connectivity solution.

Parameters for Assessment:

1. **Connectivity Percentage (%):** This denotes the proportion of time or geographical area within which the network enables devices to establish and sustain connections with the internet or other devices.
2. **Data Transmission Speed (Mbps):** Data speed gauges the rapidity at which data traverses the network, often quantified in megabits per second (Mbps). Elevated Mbps values indicate accelerated data transmission.
3. **Latency (ms):** Latency signifies the interval between sending a request and receiving a response. Typically quantified in milliseconds (ms), lower latency proves pivotal for real-time applications like video conferencing and online gaming.
4. **Initial Investment (in $1000):** This represents the upfront expenditure needed to establish the network infrastructure, encompassing costs related to equipment, installation, and other initial outlays.
5. **Operational Expenditure (in $1000):** Operational costs encompass the ongoing outlays such as maintenance, energy consumption, and other requisites to ensure the network's smooth operation.

These parameters collectively formulate a comprehensive framework for assessing the efficacy and feasibility of diverse connectivity solutions in tackling the challenges of remote and rural locales.

EDAS method: Multi-Criteria Decision Making (MCDM) has emerged as a valuable instrument for effective decision-making over the recent decades. Scholars have dedicated their efforts to refining MCDM techniques and bridging gaps that earlier methodologies might have left. Furthermore, in pursuit of more accurate and precise decisions, researchers have devised innovative MCDM models. The increasing popularity of MCDM techniques can be attributed to their inherent capability to assess numerous possibilities [13].

Within the context of a diverse array of evaluation criteria, MCDM procedures play a pivotal role in pinpointing the optimal course of action or solution. Their application extends effectively to discerning the most favorable combination of diverse process parameters that lead to the desired product qualities within manufacturing and machining industries [11,12].

In the pursuit of handling inherently conflicting process attributes, MCDM techniques can serve as tools for multi-objective optimization. This role is particularly relevant when assessing methods and experimental trials that encompass varied combinations of process conditions, regarded as viable alternatives [13,14].

The EDAS method functions by ranking available alternatives based on their positive and negative deviations from the mean solution. These deviations are computed by considering several advantageous and detrimental criteria. Preference is given to options with higher Positive Deviation from Average (PDA) values or lower Negative Deviation from Average (NDA) values [14,15].

The EDAS approach, rooted in measuring positive and negative deviations from the mean solution, forms the basis for ranking available solutions. This entails quantifying and evaluating deviations based on beneficial and unhelpful criteria. The choice to prioritize the option with a higher Positive Deviation from Average (PDA) score or a lower Negative Deviation from Average (NDA) score is considered preferable [15,16].

3. ANALYSIS AND DISCUSSION

TABLE 1.

Alternative	Ev1	Ev2	Ev3	Ev4	Ev5
Al1	65	10	50	500	25
Al2	80	5	130	750	30
Al3	90	3	80	100	10
Al4	95	15	40	350	20
Al5	85	20	30	600	28

Here Traditional Cellular Network ExpansionAl1, Satellite InternetAl2, Community Mesh NetworksAl3, NFV-based Rural Edge ServersAl4 and Hybrid Fiber-Wireless NetworksAl5 and Connectivity (%) - Ev1, Data Speed (Mbps) - Ev2, Latency (ms) - Ev3, Initial Cost (in 1000$) - Ev4 and Operational Cost (in 1000$) - Ev5.

Table 1 compares five connectivity expansion alternatives. Traditional Cellular Network Expansion offers 65% connectivity, 10 Mbps speed, 50 ms latency, with a $500,000 initial and $25,000 operational cost. Satellite Internet provides 80% connectivity, 5 Mbps speed, 130 ms latency, with higher costs at $750,000 and $30,000. Community Mesh Networks excel with 90% connectivity, 3 Mbps speed, 80 ms latency, and cost-effectiveness at $100,000 and $10,000. NFV-based Rural Edge Servers lead with 95% connectivity, 15 Mbps speed, 40 ms latency, costing $350,000 and $20,000. Hybrid Fiber-Wireless Networks offer 85% connectivity, 20 Mbps speed, 30 ms latency, with costs at $600,000 and $28,000.

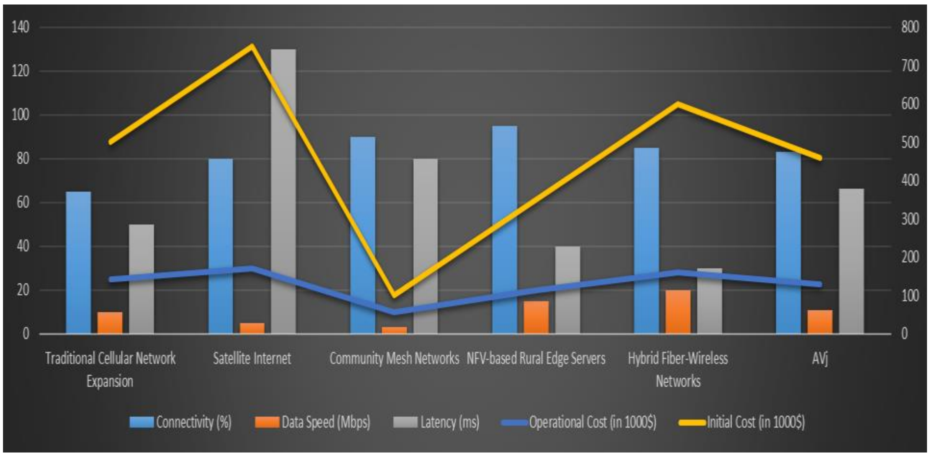

FIGURE 1.

Figure 1 illustrates a comparison among five alternatives for expanding connectivity. Traditional Cellular Network Expansion provides 65% connectivity, 10 Mbps speed, 50 ms latency, with an initial cost of $500,000 and operational cost of $25,000. Satellite Internet offers 80% connectivity, 5 Mbps speed, 130 ms latency, with higher costs of $750,000 and $30,000. Community Mesh Networks excel with 90% connectivity, 3 Mbps speed, 80 ms latency, and cost-effectiveness, requiring $100,000 initially and $10,000 operationally. NFV-based Rural Edge Servers lead with 95% connectivity, 15 Mbps speed, 40 ms latency, and moderate costs of $350,000 initially and $20,000 operationally. Hybrid Fiber-Wireless Networks provide 85% connectivity, 20 Mbps speed, 30 ms latency, with costs at $600,000 and $28,000.

TABLE 2. Positive Distance from Average (PDA)

0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.96970	0.00000	0.00000
0.08434	0.00000	0.21212	0.78261	0.55752
0.14458	0.41509	0.00000	0.23913	0.11504
0.02410	0.88679	0.00000	0.00000	0.00000

Table 2 displays Positive Distance from Average (PDA) values for five connectivity expansion alternatives. A lower PDA signifies closer proximity to the average. Traditional Cellular Network Expansion exhibits zero deviation in all aspects. Satellite Internet deviates minimally, except for latency. Community Mesh Networks demonstrate moderate deviations, particularly in initial and operational costs. NFV-based Rural Edge Servers deviate in data speed, latency, and initial cost. Hybrid Fiber-Wireless Networks notably deviate in data speed.

TABLE 3. Positive Distance from Average (PDA)

0.21687	0.05660	0.24242	0.08696	0.10619
0.03614	0.52830	0.00000	0.63043	0.32743
0.00000	0.71698	0.00000	0.00000	0.00000
0.00000	0.00000	0.39394	0.00000	0.00000
0.00000	0.00000	0.54545	0.30435	0.23894

Table 3 outlines Negative Distance from Average (NDA) values for five connectivity expansion alternatives, with higher NDA values indicating more significant deviations from the average. Traditional Cellular Network Expansion notably deviates in connectivity, data speed, and latency. Satellite Internet displays substantial variations in data speed and initial cost. Community Mesh Networks show significant deviation in data speed. NFV-based Rural Edge Servers notably deviate in latency. Hybrid Fiber-Wireless Networks exhibit substantial variations in latency, initial cost, and operational cost.

TABLE 4. Weighted PDA and SPi

Weighted PDA					SPi
0	0	0	0	0	0
0	0	0.1939	0	0	0.1939
0.0169	0	0.0424	0.1565	0.1115	0.3273
0.0289	0.0830	0	0.0478	0.0230	0.1828
0.0048	0.1774	0	0	0	0.1822

Table 4 displays Weighted Positive Distance from Average (PDA) values and their corresponding SPi values. Weighted PDA values signify positive deviations from the average, with higher numbers indicating increased divergence. SPi values represent the weighted contributions of individual parameters (connectivity, data speed, latency, initial cost, and operational cost) to the overall deviation. The figures in each row denote the specific weights assigned to these parameters in calculating the weighted PDA for each alternative.

TABLE 5. Weighted NDA and SNi

Weighted NDA					SNi
0.0434	0.0113	0.0485	0.0174	0.0212	0.1418
0.0072	0.1057	0	0.1261	0.0655	0.3045
0	0.1434	0	0	0	0.1434
0	0	0.0788	0	0	0.0788
0	0	0.1091	0.0609	0.0478	0.2177

Table 5 showcases Weighted Negative Distance from Average (NDA) values and their corresponding SNi values. Weighted NDA values indicate negative deviations from the average, with higher values suggesting more significant deviations. SNi values represent the weighted contributions of individual parameters (connectivity, data speed, latency, initial cost, and operational cost) to the overall deviation. Each row's figures denote the specific weights allocated to these parameters in calculating the weighted NDA for each alternative.

TABLE 6. NSPi and NSPi

Alternative	NSPi	NSPi
Traditional Cellular Network Expansion	0	0.5342
Satellite Internet	0.5925	0
Community Mesh Networks	1	0.5290
NFV-based Rural Edge Servers	0.5584	0.7412
Hybrid Fiber-Wireless Networks	0.5566	0.2848

Table 6 illustrates the values of NSPi (Normalized SPi) and NSNi (Normalized SNi) for five connectivity expansion alternatives. NSPi values signify the normalized positive contributions of each alternative to the overall positive deviation, where higher values suggest a more significant positive impact. Conversely, NSNi values represent the normalized negative contributions, indicating the degree of negative impact on the overall deviation. The figures for each alternative indicate the normalized influence of their specific characteristics on positive and negative deviations.

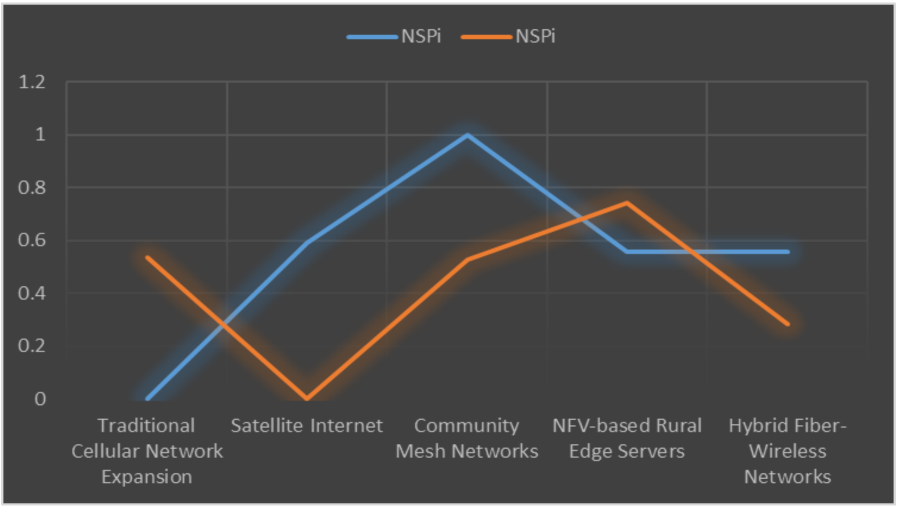

FIGURE 2

Figure 2 depicts the NSPi (Normalized SPi) and NSNi (Normalized SNi) values for five connectivity expansion alternatives. NSPi values indicate the normalized positive impact of each alternative on the overall positive deviation, with higher values reflecting a more substantial positive influence. Conversely, NSNi values portray the normalized negative impact, revealing the extent of the negative effect on the overall deviation. The numerical values for each alternative express the normalized influence of their specific characteristics on positive and negative deviations.

TABLE 7. ASi and Rank

Alternative	ASi	Rank
Traditional Cellular Network Expansion	0.2671	5
Satellite Internet	0.2963	4
Community Mesh Networks	0.7645	1
NFV-based Rural Edge Servers	0.6498	2
Hybrid Fiber-Wireless Networks	0.4207	3

Table 7 displays the Aggregated Score index (ASi) values and their respective ranks for five connectivity expansion alternatives. ASi reflects the overall performance score for each alternative, considering various criteria. Higher ASi values indicate more favorable overall performance. Community Mesh Networks lead with the highest ASi of 0.7645, securing the top rank (1), while Traditional Cellular Network Expansion holds the lowest ASi of 0.2671, ranking fifth. Ranks offer a relative comparison of the alternatives based on their aggregated scores.

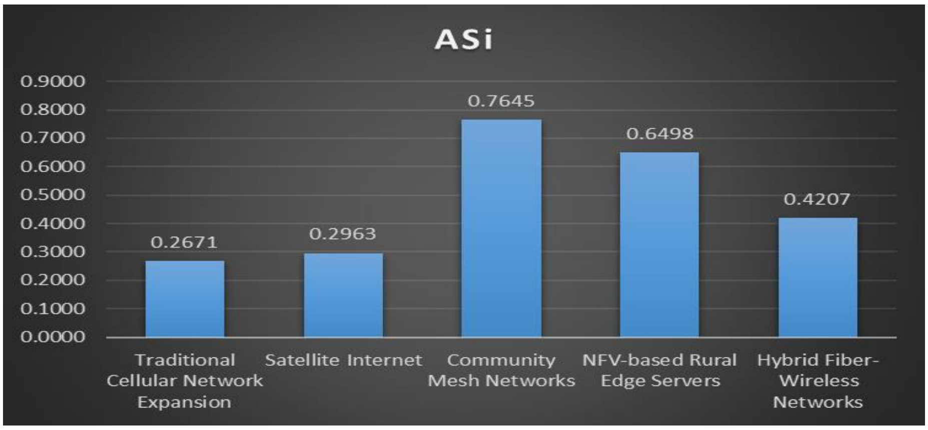

FIGURE 3

The ASi (Aggregated Score index) values for the five connectivity expansion alternatives are as follows: Traditional Cellular Network Expansion (0.2671), Satellite Internet (0.2963), Community Mesh Networks (0.7645), NFV-based Rural Edge Servers (0.6498), and Hybrid Fiber-Wireless Networks (0.4207). These scores represent an overall performance measure, with higher ASi values indicating more favorable outcomes. In this ranking, Community Mesh Networks lead, followed by NFV-based Rural Edge Servers, Hybrid Fiber-Wireless Networks, Satellite Internet, and Traditional Cellular Network Expansion.

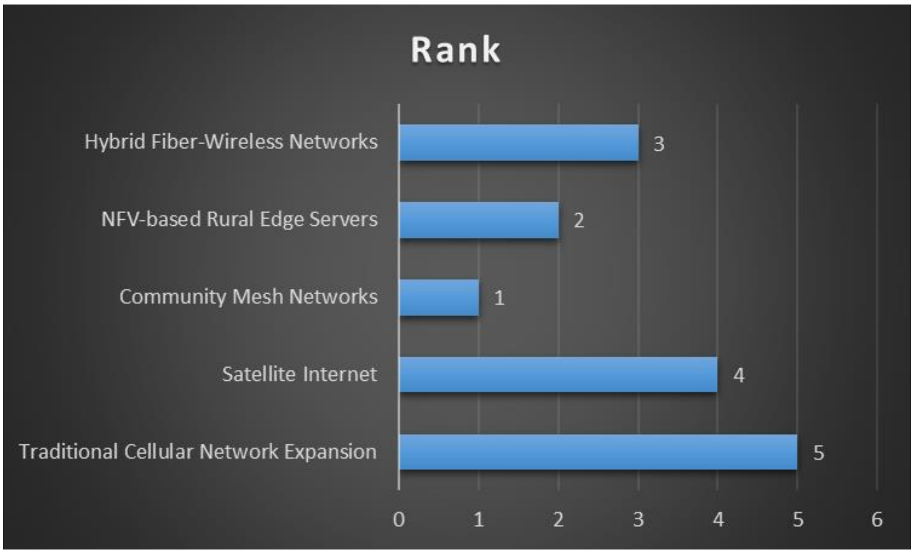

FIGURE 5

Community Mesh Networks claim the top position with an ASi of 0.7645 and rank 1. Following closely, NFV-based Rural Edge Servers hold the second rank with an ASi of 0.6498, Hybrid Fiber-Wireless Networks secure the third rank with an ASi of 0.4207, Satellite Internet takes the fourth rank with an ASi of 0.2963, and Traditional Cellular Network Expansion is ranked fifth with an ASi of 0.2671. The rankings provide a comprehensive assessment of the overall performance of each alternative.

4. CONCLUSION

In the contemporary digital era, where seamless connectivity plays a pivotal role in societal, economic, and educational advancement, addressing the digital divide in rural and remote areas is of paramount importance. This research contributes significantly to the field of telecommunications and the pursuit of digital equity. The stark disparity in connectivity between urban centers and underserved rural regions holds far-reaching consequences, impacting economic opportunities, access to essential services, and overall quality of life for rural residents.

The study, employing the innovative Evolved Data Access Systems (EDAS) methodology, explores diverse connectivity alternatives, ranging from traditional cellular network expansion to cutting-edge technologies like NFV-based Rural Edge Servers and Community Mesh Networks. Through a meticulous evaluation based on key parameters such as connectivity percentage, data speed, latency, initial cost, and operational cost, the research aims to unearth inventive approaches to enhance connectivity and communication in rural and secluded areas.

The findings, as reflected in the Aggregated Score index (ASi), provide a comprehensive ranking of the connectivity expansion alternatives. Community Mesh Networks emerge as the top-performing alternative, emphasizing their efficacy in addressing rural connectivity challenges. NFV-based Rural Edge Servers and Hybrid Fiber-Wireless Networks follow closely, highlighting the potential of virtualized networks and hybrid solutions. The research underscores the critical need for tailored connectivity solutions in rural areas, considering factors such as data speed, latency, and cost-effectiveness.

Addressing the rural digital divide not only facilitates socioeconomic development but also has broader implications for education, healthcare, e-commerce, and governance. Bridging this gap aligns with global efforts towards sustainable development and ensures that the benefits of the digital age are accessible to all, irrespective of geographical location. The study suggests that continued research and implementation of innovative connectivity solutions, guided by methodologies like EDAS, are crucial for narrowing the digital divide and fostering inclusive development across diverse communities.

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