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Open Radio Access Network (ORAN) Deployment Strategies for Remote Areas

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Abstract
Extension of mobile coverage to sparsely populated rural and remote regions remain a global priority and presents unique challenges. This is due to the low population density; limited terrestrial backhauls and intermittent power associated with these regions. The disaggregation, open interfaces, RIC/SMO automation and potential cost-efficiencies of Open RAN promise architectural flexibility to improve economics and operations of Open RAN in rural and remote environments. This paper presents a systematic literature review of Open RAN deployment strategies in rural and remote areas. The review synthesizes academic studies, industry white papers, vendor/operator case reports and analyst studies. The literature supports strategies that include: (1) models that support infrastructure (Spectrum and Site) sharing integrated with renewable power sources and energy-aware features to manage OPEX and site autonomy (2) cloud-native DU/CU placement at regional edge sites combined with site local intelligence (RIC/SMO) for energy and radio optimization. (3) Hybrid backhaul using fiber/microwave for high-capacity node and satellite link or TVWS as backup or last-mile connection. Open RAN can make rural coverage more cost-effective when deployments are carefully designed using topology-aware functional splits, hybrid backhaul architectures, shared infrastructure models, robust SMO/RIC automation, and renewable energy solutions. Significant gaps persist in standardized TCO assessments and long-term, multi-vendor operational studies for rural and remote deployments.

Keywords: *Open RAN, rural deployment, functional split, SMO/RIC, neutral-host.*

1.0 Introduction

Mobile access remains uneven globally. The low mobile connectivity penetration in rural and remote regions is associated with its low population density, inadequate economically viable terrestrial infrastructure and low Average Revenue Per User (ARPU), which reduces Mobile Network Operator (MNO) incentives to invest in RAN infrastructure in these regions [1]. Open RAN (ORAN) through its disaggregated open radio unit (RU), distributed unit (DU), centralized unit (CU), open interfaces and Service Management and Orchestration (SMO)/Radio Intelligent Controller (RIC) automation promises architectural flexibility that enables vendor diversity and sharing models suited to rural economics [2], [3]. However, its deployment in rural and remote context present unique challenges that requires tailored strategies. This review synthesizes literature on the architecture, backhaul/power options, sharing/business models, challenges, benefits, comparative performance and field evidences to derive practical deployment strategies of Open RAN suited for rural and remote areas.

2.0 Key Deployment Strategies

2.1 Technology Adaptation

Open RAN's disaggregated, cloud-native and programmable architecture can significantly improve the flexibility and economics of rural and remote mobile coverage when its deployment adapts explicitly to certain constraints such as low-density traffic, constrained power and limited backhaul etc. associated to these regions. Targeted technical choices relating to automation, energy management, fronthaul/backhaul selection, edge/cloud placement, and interoperable testing have been identified to substantially overcome some of the challenges. Empirical pilot projects and operator greenfield builds [4] demonstrate feasibility when technology adaptation is combined with supportive spectrum and financing policies.

2.1.1 Open RAN architecture, SMO and edge placement

SMO and RIC (Non-RT and Near RT), a key feature of Open RAN play a critical role in enabling operational automation and policy guidance in Open RAN. They enable intent driven lifecycle management, policy-based guidance, AI/ML workflows and data driven optimization that are essential to OPEX reduction in distributed multi-vendor deployments [5]. The authors in [5] for example, proposed that O-RAN's SMO are capable of reducing RAN OPEX by up to approximately 10 percent for a brownfield over a period of 5 years. For rural deployment scenario, [1] and [6] recommends edge localized O-DU/O-CU placement (regional edge cloud or small regional data centers) to balance fronthaul constraints and latency, while retaining SMO/Non-RT RIC

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centrally (or shared regionally) for ML model training and near-RT RIC at a regional edge to support rapid local control loops [6].

2.1.2 Energy Management

Remote base stations cost substantially more (approx. 35 – 40%) to run when compared with corresponding urban sites, with higher diesel dependency driving OPEX and carbon intensity. Tackling energy cost and promoting energy management is central to ensuring sustainability of rural network [7]. The whitepaper as in [8] surveys potential energy saving features that can be implemented within O-RAN architectures and explains how O-RAN's disaggregation and intelligence (SMO, Non-RT RIC rApps, Near RT RIC xApps) create control points to reduce energy consumption without degrading user experience. It frames energy reduction across two domains: (1) RAN radio/hardware (O-RU level: transmit power, antenna/TRX scaling, sleep modes, dynamic voltage/frequency adaptation), and (2) compute/cloud resources (O-Cloud workload placement, CNF scheduling, energy aware scaling). It draws conclusion on how O-RAN's open and software driven architecture converts previously static energy levers (e.g., cell on/off, power amplifier settings) into programmable policies that can be optimized at multiple timescales (near real-time via xApps and long term via rApps) to enable coordinated energy savings across RU, fronthaul and cloud resources.

In order to reduce the base station's dynamic power consumption in an O-RAN environment, the authors in [9] proposed the O-RAN Rapid Transition Protocol (ORTP), a DU-level protocol that initiates earlier handovers through a reduced handover margin (HOM) of 2 dB. Although, the authors reported an approximate 20 percent reduction in dynamic RAN power consumption through its 5G system-level simulation, more field tests are needed to verify the claim. Similarly, the results are highly dependent on simulation assumptions (HOM values, user rate/distribution, traffic models, etc.), and do not quantify the signaling burden and user experience risks brought about by the increase in handover frequency. Furthermore, the "interoperability" conclusion lacks cross-vendor empirical support.

GSMA positions energy as a key lever for improving rural operator free cash flow and long-term investment capacity. The authors in [7] argued that renewable energy deployments when paired with innovative financing, tower companies, and public support can both lower OPEX and support broader social and economic benefits from improved connectivity. It further provides dual emphasis on technical feasibility and commercial/finance structures, citing technology alone (solar/battery hybrids) as insufficient without a viable commercial model and multi-stakeholder partnerships. The report outlines pragmatic models to make rural renewable rollouts viable. This model comprises of mixed energy system (solar, battery and limited genset), in partnerships with tower companies and blended finance through grants, concessional loans, carbon linked revenues, etc, and collaboration with governments.

2.1.3 Functional Splits and Constrained Fronthaul

Lower layer splits (near PHY) demand very low latency and high bandwidth. This is often infeasible where fronthaul uses satellite or long microwave hops. To overcome this requirement, pragmatic split choices such as a higher layer splits where fronthaul has a high latency and dynamic split placement driven by SMO policies to adapt to changing backhaul conditions is recommended in [1].

2.2 Infrastructure Sharing Model

Sharing infrastructure and resources (active and passive) between multiple mobile network operators (MNOs) can reduce deployment costs and improve service quality [10]. Several authors have proposed sharing models in ORAN. For example, the authors in [11], [12], [13], [14] offered complementary insights into MORAN and MOCN network-sharing frameworks. Specifically, 3GPP provided standardized architectural definitions and signaling procedures for implementing shared network infrastructures [14]. GSMA addressed the economic, regulatory, and deployment considerations associated with these sharing models [13]. The author in [12] meanwhile, highlighted the commercial potential of neutral host networks and Open RAN, although it offers limited quantitative analysis or interoperability validation for MORAN and MOCN deployments.

Fundamentally, MORAN enables the sharing of radio access network (RAN) hardware while allowing each operator to retain independent spectrum resources and core network functions, thereby preserving operator-specific policy differentiation. In contrast, MOCN supports shared RAN infrastructure combined with spectrum pooling and multiple Public Land Mobile Network (PLMN) identifiers, enabling several operators to deliver services through the same RAN platform [12], [13]. Despite the technical comprehensiveness of 3GPP specifications, a notable limitation is the absence of empirical evaluation regarding signaling overhead, system performance, and multi-vendor interoperability in real-world deployments. This restricts robust quantitative assessment of operational risks, implementation complexity, and associated costs [14].

Similarly, GSMA's industry-focused cost and policy models provided useful guidance for regulatory and strategic planning; however, their cost-saving projections are primarily based on simulations and third-party market analyses. As such, these estimates require validation against localized market conditions and measured operational data before being applied in rigorous policy decision-making [13]. The author in [12] contributed valuable business-oriented perspectives, yet its discussion of spectrum allocation, signaling load, service-level agreement (SLA) impacts on quality of experience (QoE), and the technical interoperability mechanisms underlying MORAN/MOCN lacks sufficient analytical depth. Consequently, its findings are more appropriately referenced as industry insight rather than as empirical technical evidence [12].

The authors in [15] in their response to the growing inefficiency of maintaining separate infrastructure particularly in highways and rural areas proposed and positioned "OneRAN – a One Radio Access Network" approach (involving the complete pooling of RAN resources and spectrum for outdoor wide area coverage) as a technical and economic alternative to per-operator infrastructure ownership and partial RAN sharing models. This was established through analytical modelling, field measurement campaign and comparative analysis of the analytic trunking/flow models with measured LTE KPIs (for three commercial Finnish MNOs over a 52 km highway corridor). The authors emphasized that, at flow level, pooling identical operator resources yields multiplicative throughput benefits and that these theoretical gains can translate to noticeable improvements for cell edge/highway users in practice. Although the paper argues CAPEX/OPEX savings through the reduction of sites/mast count, shared RAN equipment, shared maintenance and operation costs, detailed vendor-agnostic TCO models, sensitivity analyses, and transition costs (legal, regulatory, contractual) are not exhaustively modeled, and as such constrains economic conclusions. In addition, real operational issues such as: multi-operator governance, spectrum licensing, inter-operator SLAs, core network integration, roaming etc. are only discussed qualitatively rather than a live multi-operator pooled testbed. This gap can affect the feasibility. and net gains in practice.

The authors in [16] presented a comprehensive survey and tutorial on O-RAN with a focused treatment of network slicing. It reviewed O-RAN Alliance specifications, related SDOs and open-source contributions, and recent research to characterize slicing-aware Open RAN architectures, deployment options, orchestration choices for RAN/transport subnets, use cases, and open challenges. The paper extensively discussed infrastructure slicing (virtualized resources, multi-tenant PoPs) and assembles representative use cases (e.g., eMBB, uRLLC, mMTC, industrial/private networks) showing differing requirements for slice isolation, latency and reliability. The authors emphasized that slicing in O-RAN is inherently multi-domain, spanning the Radio Access Network (RAN), Transport Network (TN) and the Core Network (CN) and that meaningful E2E slicing work must therefore align contributions across multiple SDOs and open-source projects. Although the paper qualitatively identifies many trade-offs such as with placement, isolation and orchestration, it does not quantify performance, cost, or energy implications by experiments or models. Similarly, no primary experimental measurements or simulations was reported.

Furthermore, RAN sharing enabled by Open RAN disaggregation allows multi-tenant RU/DU setups and containerized vRANs. It allows different operators to run independent software stacks on shared hardware [7].

2.3 Hybrid Model

Hybrid model have been proposed in literature for Open RAN deployment in Rural and remote Area. The scope encompasses hybrid backhaul and a mix of targeted Open RAN for rural region and legacy RAN for urban region. Operators isolate Open RAN to rural clusters where legacy interdependencies are low while keeping traditional vendor RAN in urban/macro markets. Pilot project by Orange in Romania shows that the model reduces migration friction and maintains stability where needed [17].

The authors in [18] proposed fiber or microwave to aggregation nodes where available. Satellite (GEO/MEO/LEO) is also recommended for last mile, backup, or where terrestrial is uneconomic. Analyst studies quantify that satellite will be a significant enabler for remote backhaul but with cost and latency trade-offs. LEO offers lower latency than GEO but brings operational challenges vis-à-vis handover and possible higher short term bandwidth costs. NTN/LEO research highlights RAN functional split and handover complexities when using regenerative LEO architectures; these influence latency budgets and the feasibility of low layer splits over satellite links [18].

Aside the aforementioned backhaul technologies, TV White Space (TVWS) is also presented in [4] as a promising backhaul technology for consideration in the rural and remote areas. Although the author recorded a 100 percent deployment success rate for the seven (7) planned sites, the public GSMA/NuRAN papers are largely descriptive with limited publicly available metrics. Granular technical KPIs such as throughput and availability, user behavioral data, and detailed financials (CAPEX/OPEX, ARPU, payback) are not published in full. This constrains external evaluation of performance and commercial sustainability claims.

Table 1 provides an overview of some technological adaptation/ strategies for Open RAN deployment in rural context.

Table 1: Overview of some technological adaptation/Strategies for Open RAN deployment in rural context

Scope/Deployment Strategy	Author(s)	Scenario	Typical Infrastructure (Backhaul/Power)	Key Benefits	Limitation
Cloud native Greenfield Open RAN	[1], [4], [19]	New greenfield rural projects with operator control	Integrated Regional edge Cloud with Fiber/Microwave backhaul where available or	High automation and vendor choice Rapid Continuous integration and continuous Delivery Simpler orchestration upon automation	Requires strong integration and cloud operations expertise [20], along with upfront CAPEX investment in cloud infrastructure and automation systems.
Phased/incremental Roll out strategy employing cloud/edge achitecture with SMO	[5]	Employed multi-generation hybrid RAN (physical, vRAN/Cloud RAN) and multi-band, multi-slice service scenarios	Fiber/microwave,	Fast deployment with the adoption of cloud and SaaS models. SMOs reduce RAN OPEX and enable cross-vendor closed-loop automation through standardized interfaces and rApps.	Findings are based on architectural arguments, customer discussions, and case studies
Energy Optimization/Management	[9]	5G system-level simulation to test different user speeds, TTT and HOM settings.	Assumed a typical O-RAN architecture with a separate RU/DU/CU, which relied on RIC/SMO that supports policy-based deployments, and used conventional fiber/microwave links for backhaul	ORTP achieved a dynamic energy consumption reduction of approximately 20% by decreasing HOM. Easy to deployment	Relied heavily on controlled system-level simulations and lack multi-vendor interoperability testbeds and real-world data on actual traffic, different frequency bands, and various deployment densities
	[8]	Testbed in scenarios with frequent handovers or significant load	Assumed a separate CU/DU/RU O-RAN architecture, edge/cloud platform and conventional fiber/microwave	Facilitates policy iteration and centralized monitoring via rApps to improve energy	Offered normative recommendations, but devoid of empirical guidance on field backhaul and power

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Scope/Deployment Strategy	Author(s)	Scenario	Typical Infrastructure (Backhaul/Power)	Key Benefits	Limitation
		fluctuations	backhaul. Emphasized power state management of wireless units as the principal optimization objective.	efficiency measurability. Allows for more precise sleep and carrier management to lower RAN power consumption	constraints, quantitative analysis of signaling/delay overhead, and large-scale multi-vendor test data
Brownfield overlay Open RAN	[11], [21]	Established operators operating legacy RAN infrastructure	Leverage existing backhaul technology while microwave/satellite is integrated for last hop.	Phased investment approach with minimal operational disruption	Integration complexity with legacy vendors and limited short-term cost benefits.
Infrastructure Sharing (Neutral host — MOCN (spectrum pooling multi-tenant))	[12], [13], [15]	Rural clusters serving multiple operators or shared public infrastructure deployments.	Shared backhaul infrastructure in addition to pooled power arrangements	Significant CAPEX and OPEX sharing with improved spectrum utilization.	Complex SLAs, inter PLMN orchestration & pricing.
MORAN (shared RAN, separate spectrum)	[12]	Rural network sharing requiring regulatory compliance and operator isolation.	Shared physical RAN but separate spectrum	Simpler Ops compared to MOCN with reduced short-term integration risk	Lower spectral efficiency
Satellite-enabled micro sites (LEO/GEO hybrid)	[18]	Sites with no terrestrial backhaul or where terrestrial backhaul is not feasible	LEO/MEO/GEO terminals with local RU integrated with solar power	Fast deployment and ubiquitous reach	Trade-offs between latency and cost Terminal reliability RAN split constraints over NTN
Slice-aware architecture and phased commercial deployment	[16]	Focused on multi-tenant network slicing, cloud–edge integration, and AI-driven closed-loop	Assumed vRAN architecture with separate CU/DU/RU, SMO/non-real-time RIC deployed on the edge/cloud platform, and backhaul primarily	Achieved cross-vendor automation, slice-aware resource orchestration, energy efficiency, and QoS	Focused on literature review standards and simulation but lacked large-scale multi-vendor field tests and measured data to

Scope/Deployment Strategy	Author(s)	Scenario	Typical Infrastructure (Backhaul/Power)	Key Benefits	Limitation
		control, with applicability to hybrid 4G/5G and industry-specific use cases.	using fiber/microwave. Power consumption and edge computing power were the primary optimization targets	optimization with the utilization of open interfaces, rApp/xApp, and the SMO ecosystem.	quantify interoperability, signaling overhead and economic benefits under different market conditions
Edge-consolidated DU/CU with SMO/RIC	[1], [6]	Regional clusters requiring low latency	Regional edge deployment with resilient backhaul and solar/backup power solutions.	Enables low latency control loops, energy optimization and automation	Requires edge infra which may be costly and skilled cloud technical know-how (ops)

2.4 Living labs, testbeds & prototypes

Hybrid end-to-end living Labs and prototype campus networks have been deployed in literature to validate energy, fronthaul/backhaul and multi-vendor interoperability before scale roll out. The GSMA-backed NuRAN pilot presented in [4] depicts a practical experiment to test low-cost, low-power mobile broadband infrastructure for deep rural communities in Northern Ghana. The project is notable for combining technology with low power RAN, TVWS backhaul, and Open RAN principles in partnership with local partners and donor funding to de-risk rural deployments. The pilot shows that technical and stakeholder coordination levers are treated jointly rather than as separate problems. While the pilot demonstrates technical feasibility and strong early uptake, its published evidence is descriptive with limited public metrics, TCO or independent evaluation. Therefore, further transparent performance, cost and scalability studies are needed.

The authors in [1] combines a broad, standards aware survey with practical prototyping to bridge theory (specs, functional splits) and practice. The authors developed two campus scale 5G prototype networks using commercial off the shelf (COTS) hardware and open-source software stacks.

3.0 Challenges and Barriers

Deployment of RAN infrastructure in rural and remote areas poses a unique challenge which are related to low population density, low income, difficult terrain, inadequate and nonexistent infrastructure, and lack of power grid, all of which have brought about low digital penetration in these areas [22]. One major factor for MNOs is the low ARPU which dampens the Mobile Network Operator's willingness to invest in these areas. These challenges are discussed in the leading sections.

3.1 Infrastructure and Cost Barriers

The availability of infrastructures in the remote and rural areas are a major challenge to the extension of connectivity to these areas. These are further discussed under the headings:

3.1.1 Upfront Capital

Rural and Remote location are associated with low population density which accounts for low ARPU and Rural site cost approximately 35-40 percent more to operate when compared with an urban counterpart [23]. These costs are largely OPEX for power, transport, site maintenance etc. The Author [24] argued that RAN constitute about 70-80 percent of the TCO of the mobile network. It implies that cost savings on RAN deployment will represent an opportunity to reduce the overall network cost. He presented the financial benefits of Open RAN under three (3) sub areas: (1) Cost of open radio, (2) Cost of Open RAN software which will cost 30 percent less and (3) Cloud server.

3.1.2 Backhaul constraints

Rural/remote backhaul is often either scarce, costly or absent. Fiber for example is rare; terrestrial wireless links require many hops or line-of-sight; satellite provides coverage but has cost/latency trade-offs. These realities drive Open RAN architectural choices and site economics [23]. Open RAN adds explicit fronthaul/midhaul interfaces e.g., O-RAN 7.2x, eCPRI and supports split-by-site strategies, which allow adaptation to constrained transport provided they are matched to the chosen split. Therefore, practical rural deployment require a transport-aware deployment plan [25].

3.2 Technical limitations

3.2.1 Radio availability and multi band radios

Scarcity or mismatch of ruggedized, multi-band O-RUs that cover the low-band frequencies (600 – 900 MHz) used for rural coverage, in conjunction with constraints on power, size, and antenna integration is a major technical limitation for Open RAN rollouts in remote and rural areas. These radio limitations forces conservative functional-split choices, increase site OPEX (power, mounts, spares), complicate fronthaul requirements, and drive procurement and interoperability risk [1], [4]. For example, constrained or high-latency favors higher-layer splits (e.g., Option 2 / DU at site) or local DU placement to keep time-critical PHY/HARQ loops local. This RU capability directly constrains what split the operator may safely choose. In situations where integrated wideband RUs are scarce, GSMA proposes the deployment of high-quality passive combiners or dedicated low-band RUs with mid-band RUs at shared towers with combiner losses and RF margin adequately quantified during planning [4].

3.2.2 Energy and robustness

Consistent power (solar/backup system) and ruggedized equipment are required for unattended sites as in the case of remote locations. To overcome this limitation, [9] proposed a well-established energy-aware RIC/ORTP approaches.

3.3 Regulatory and policy issues

Policies and rules affecting spectrum allocation/pricing, security and supply-chain, certification/procurement regimes, infrastructure/permitting and public funding models are decisive determinants of whether Open RAN can be adopted cost-effectively and at scale in rural and remote areas. A careful analysis of these policies is of utmost importance.

3.3.1 Spectrum and licensing:

Spectrum policy affecting availability, band, pricing and term certainty is the most direct determinant of rural coverage economics. The availability and affordability of low band (sub 1 GHz) long term assignments substantially improve the business case for rural sites without which operators may avoid rural expansion or use complex multi-site designs (more RUs, more power) [26]. In addition, policies for pooling or multi operator core/shared spectrum (MOCN, etc.) vary by jurisdiction and can slow neutral host/OneRAN model implementation [23].

3.3.2 Procurement and security rules:

Some governments restrict equipment choices (on security grounds) or have procurement rules that disfavor multi-vendor or third-party neutral hosts. These can complicate Open RAN adoption in rural subsidy programs. To mitigate the impact, the following recommendations were suggested in [27] - alignment of security testing with industry certification, usage of risk-based approaches that balances security with vendor diversity.

3.4 Benefits of Open RAN Deployment in Rural and Remote Area.

Outlined in the following subsections are the key benefits of Open RAN deployment in rural and remote areas.

3.4.1 Cost efficiency

Pooling/shared infrastructure reduces cost per subscriber and can make previously unviable sites viable. OneRAN pooling demonstrates higher theoretical/observed throughput and reduced percentage of cell edge users below target throughput [15].

3.4.2 Improved connectivity and service reach:

Case studies show small footprint Open RAN sites (neutral host micro sites) can rapidly eliminate local hotspots and provide multi operator coverage [28]. Energy optimization and ORTP-like approaches can reduce power consumption while preserving performance — improving sustainability for remote sites [29]. The authors in [9] presented in their simulated scenarios that the ORTP strategy (selecting lower Hand Over Margin - HOM values) reduced dynamic RAN power consumption by approximately 20% compared to the baseline 5G configuration reported.

3.4.3 Economic and Social impact:

Improved rural coverage delivers measurable socio-economic benefits that impacts education, health, commerce, etc. GSMA highlights how energy and financing partnerships (telcos, tower companies, energy specialists, government) are key to driving rural rollouts and local economic benefit [23].

4.0 Recommendation for Stakeholders

Recommendations for the various stakeholders are outlined in the subsequent sub-sections.

4.1 For Policymakers

It is recommended that polices that favors shared-infrastructure and clear frameworks for neutral host and pooled spectrum (MOCN/Commercial neutrality) be enabled to unlock operator participation [23]. Similarly, grant/financing that combines telecom and renewable energy funding is recommended by [29] to lower OPEX risk for remote sites. Furthermore, initiatives that support testing, prioritization of standards coordination, R&D partnerships and international coalitions is suggested [30].

4.2 For MNOs and TowerCos

Pilot projects involving isolated Open RAN clusters (rural pilots) and neutral host micro sites is recommended by [31] to validate vendor stacks and energy systems before wider migration. Living labs are suggested for the collection of KPIs. The adoption of RIC based energy and mobility optimization (ORTP style policies) to reduce site OPEX and improve handover/coverage quality is recommended by [9].

4.3 For Vendors/Integrators

The authors in [29] recommends adoption of ruggedized, multi-band low power RUs, simplified zero touch provisioning with validated interoperability stacks for rural footprints. Investment in Open Testing and Integration Centre (OTIC)/qualification is also recommended to lower integration risk.

4.4 For development agencies and funders

Funding for PoC programs combining neutral host business models, renewable power, and local capacity building should be embraced with socio-economic KPIs measured as part of pilot design [12].

5.0 Gaps in Research/Future Direction

i. Long-Term, real-world multi-vendor Open RAN rural deployments: Many results remain simulation/prototype-based as stated in [1] with few peer-reviewed, long-term field studies benchmarking commercial KPIs such as availability, TCO, lifecycle and OPEX.
ii. Standardized KPI sets for rural Open RAN pilots: Heterogeneity in metrics impedes cross-study comparison. KPIs like CAPEX/OPEX, availability, cell edge throughput, energy per GB etc. should be defined [23]. ORAN Alliance Group and GSMA recommended the adoption of a common KPI framework for pilots.
iii. Security and SLA enforcement for neutral host multi-tenant deployments at scale: More operational research is required on SLA frameworks and end-to-end security in multi-vendor stacks.
iv. Limited research-based evidence on detailed socio-economic impact evaluations tied to technical design choices e.g., Open RAN strategy and the corresponding community outcomes/impact [20], [32].

6.0 Conclusion

Open RAN provides a flexible architectural foundation to extend coverage to rural and remote areas. Its success however, depends on tailoring deployments to topology and constraint realities. The use of adaptive functional splits, hybrid backhaul (including satellite and TVWS where required), SMO/RIC driven automation for energy and performance, renewable energy systems and sharing models that align commercial incentives are proposed in [1], [6], [29]. Key gaps remain in standardized TCO comparisons and long-term multi-vendor operational studies in rural and remote contexts.

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