Towards a Guinean Research and Education Network (Gren): A Digital Bridge between Universities

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ABSTRACT
In an era where digital infrastructure is essential for academic excellence and scientific progress, Guinea faces the strategic challenge of interconnecting its higher education institutions to foster collaboration, innovation, and equitable access to knowledge. This article explores the vision, opportunities, and challenges of establishing a Guinean Research and Education Network (GREN) a national digital infrastructure designed to link public universities and research institutions across the country. The study outlines the technological, institutional, and policy frameworks needed to implement such a network, drawing on best practices from other National Research and Education Networks (NRENs) around the world. It emphasizes the potential of the GREN to become a digital bridge, not only between Guinean universities but also with regional and global research communities. Through this initiative, the article argues, Guinea could significantly enhance academic collaboration, optimize research outputs, and improve digital access for students and faculty. The paper concludes by recommending key steps for government agencies, universities, and partners to take in order to launch and sustain the GREN as a cornerstone of Guinea's digital transformation in higher education.

Keywords
GREN, NRENS, BGP, MPLS, GÉANT, AfricaConnect, GNS3, UBUNTUNET.

1. INTRODUCTION
In a global context marked by the rapid rise of digital technologies in higher education, National Research and Education Networks (NRENs) plays a central role in scientific development, human capital training, and the internationalization of universities. The growing importance of advanced services provided by NRENs is a key factor that sets them apart from those offered by commercial Internet Service Providers (ISPs). Unlike basic connectivity, these advanced services are specifically designed to address the complex needs of research and education communities. NRENs enable the pooling of digital resources, support the efficient transfer of large-scale datasets, and facilitate remote scientific collaboration. Through these capabilities, NRENs have become essential infrastructures, driving scientific innovation and making significant contributions to the global advancement of knowledge [1]. These NRENs play a vital role in developing communication infrastructure and reducing digital divides, supporting researchers and educators both nationally and internationally. A survey conducted as part of the TANDEM (TransAfrican Network Development) project, in collaboration with WACREN (West & Central African Research and Education Network), revealed that researchers in the region have a strong need for regular access to online conferences, academic resources, collaboration services, and remote computing capabilities. However, poor network connectivity remains a major obstacle meeting these needs [2]. Many African countries have recognized the strategic importance of National Research and Education Networks (NRENs) in achieving their higher education development objectives. For instance, the South African National Research and Education Network (SANReN), as highlighted by Kevin Draai et al. [3], and the Kenya Education Network (KENET), as discussed by Aseda et al. [4], have made significant progress in improving campus connectivity, expanding access to open science, and deploying advanced digital services. In Kenya, although open science promotes accessible and collaborative research, its adoption remains limited due to insufficient training and a lack of awareness. To address these challenges, the sensitize-train-hack-collaborate model developed in Nairobi offers a promising approach to encourage and support the practice of open science in the country [5]. AFRICACONNECT brings together three advanced networks UBUNTUNET, WACREN, and ASREN which interconnect the National Research and Education Networks (NRENs) across 29 African countries. This project has supported the development of backbone infrastructures, the integration of IPv6 connectivity, and the evaluation of network performance through GNS3 emulation. These advancements provide valuable insights for strategic decision-making in the development of high-performance networks, including for Internet Service Providers (ISPs) [6]. Ubuntunet Alliance is a regional research and education network in Eastern and Southern Africa, focused on interconnecting National Research and Education Networks (NRENs) to enhance scientific collaboration and access to global digital resources [7]. By connecting to international infrastructures like GÉANT, it provides African universities with high-quality broadband. Its main goal is to reduce the digital divide by offering fast, affordable internet to academic institutions while promoting regional and international scientific cooperation. The Arab States Research and Education Network (ASREN) is a regional network that interconnects the National Research and Education Networks (NRENs) of Arab countries to strengthen scientific cooperation and provide high-speed connectivity. By linking to international networks like GÉANT and Ubuntunet, ASREN gives universities and research institutes access to global scientific resources. Its

mission includes developing advanced communication infrastructure, encouraging resource sharing, reducing the digital divide, and supporting regional and international collaboration in research and education [8]. The design of a fully resilient campus network in Ghana focuses on supporting research and education by minimizing downtime caused by system failures or device upgrades. By duplicating all critical devices to eliminate single points of failure, the network guarantees uninterrupted service and is scalable to accommodate increasing bandwidth demands over seven years. Concurrently, Ghanaians have developed their own university network to further enhance academic connectivity and foster collaboration [9]. GÉANT, the pan-European Research and Education Network, and AfricaConnect, a major initiative co-funded by the European Union to develop and expand high-speed research and education networks across Africa, are advanced infrastructures that interconnect 72 countries across Europe and Africa through continuously evolving high-bandwidth networks. This study emulated the combined 2020 IPv6 topology of GÉANT and AfricaConnect using GNS3, demonstrating the emulator's effectiveness for network analysis even in environments with limited computing resources [3]. In Togo, a study was conducted in the same direction to propose a suitable architecture for a National Research and Education Network (TogoRER), based on an analysis of the internet coverage across public and private higher education and research institutions. This approach takes into account the country's technical realities and draws inspiration from successful experiences in other countries to enable effective interconnection with the regional network WACREN. The objective is to allow researchers, teachers, and students in Togo to collaborate more efficiently through fast, reliable, and secure access to scientific resources [10].

While higher education and research in Guinea have seen gradual development in recent years, the absence of a national communication infrastructure dedicated to research and education severely limits the performance of universities. Data exchange, collaborative projects, access to high-quality digital resources, and participation in international scientific initiatives remain highly constrained. As several studies have shown the lack of a robust academic communication network as a major obstacle to the scientific competitiveness of developing countries. In Guinea, institutions such as ANSUTEN and ARPT have launched various initiatives most notably, the Univ-Connect project to provide universities with fiber-optic connectivity. However, the lack of a coherent and centralized institutional, technical, and financial framework continues to hinder the establishment of a Guinean National Research and Education Network. Currently, the country does not have a sufficiently structured academic infrastructure to effectively support collaborative research, facilitate access to international scientific resources, or integrate into major digital alliances such as Ubuntunet or GÉANT. As Mutula et al. [11] emphasizes, the integration of African universities into regional and global research networks is essential for closing the academic digital divide. To support efforts aimed at reducing the digital divide, this study explores the connection between various emerging technologies and the persistent digital gap in Africa, using recent data from the International Telecommunication Union (ITU). Recognizing the unequal access to ICTs as a complex and multifaceted issue, it draws on examples of technology deployments across the continent to identify effective solutions. Notable cases from countries such as Tanzania, Malawi, and South Africa serve as references for recommending best practices in networking technologies that could inform similar initiatives, including the development of research and education networks like TogoRER. In light of these challenges, this article proposes a strategic reflection on the creation of a Guinean Research and Education Network (GREN). It draws on a comparative analysis of other countries' experiences, identifies the technical and institutional feasibility conditions, and outlines a roadmap to make GREN a true digital bridge between Guinean universities, while connecting them to the global scientific community.

2. BACKGROUND ON NATIONAL RESEARCH AND EDUCATION NETWORKS (NREN) IN AFRICA

2.1 Definition and Strategic Role of NRENs

National Research and Education Networks (NRENs) are digital infrastructures dedicated to the interconnection of higher education and research institutions. Unlike commercial internet service providers, NRENs offer specialized services such as access to international scientific resources [12] [13] , high-performance computing, distributed storage, identity federation systems like eduroam (Eduroam, for education roaming, which is a global secure Wi-Fi roaming service for the international research and higher education community. It enables students, teachers, researchers, and academic staff to access the Internet via Wi-Fi at any eduroam member institution using the same login credentials as their home university automatically, securely, and without additional configuration) [14], and academic videoconferencing. They are key pillars of the digital transformation of universities in many countries Mutula et al.[11] . According to Oyelaran-Oyeyinka the absence of a high-performing academic network constitutes a major barrier to the emergence of national innovation systems in developing countries [15]. In the African context, NRENs are also recognized as catalysts for regional scientific cooperation and for the inclusion of African universities in global initiatives such as GÉANT, WACREN, or UbuntuNet Alliance.

2.2 Successful Experiences in Africa

The South African National Research and Education Network SANReN [16], [17], launched in 2005, is one of the most advanced NRENs on the continent. It is operated by the Council for Scientific and Industrial Research (CSIR) in partnership with TENET (Tertiary Education and Research Network of South Africa). SANReN provides connections of up to 100 Gbps and enables participation in major international projects such as the Square Kilometer Array (SKA) [18]. Thanks to substantial public funding and clear governance, SANReN has enabled the widespread adoption of digital services in South African universities. Established in 1999, the Kenya Education Network (KENET) is a model of academic governance. It connects over 80 institutions and provides Internet access, academic cloud services, cybersecurity, and e-learning tools. KENET has played a crucial role in improving access to high-speed Internet, hosting MOOCs, and organizing technical training [4]. One of its major achievements is the reduction in bandwidth costs for universities through shared infrastructure and resource pooling. Open Science, as defined by UNESCO, aims to make scientific research and data accessible to all, but its adoption in Kenya is limited due to a lack of awareness, training, and integration into university curricula [5]. Through the OpenScienceKE framework, a sensitize-train-hack-collaborate model was implemented to promote Open Science practices in Kenya, revealing low participation in preprint publishing and highlighting persistent barriers such as limited skills and awareness that need to be addressed to advance Open Science in the region [5]. The Mozambique Research and Education Network (MoRENet) was created in 2012 with

support from the World Bank [19], [20],[21]. It connected 24 higher education institutions nationwide and enabled the hosting of critical services such as university management platforms and research portals. MoRENet also benefits from a national Data Center, which strengthens the digital autonomy of universities. The Research and Education Network for Uganda (RENU) has become a regional benchmark thanks to its strategy focused on network engineer training, identity federation (eduID), and interconnection with digital libraries [22]. RENU is an active participant in the UbuntuNet Alliance and deployed a large-scale videoconferencing system during the COVID-19 pandemic.

2.3 Success Factors of African NRENs and Specific Challenges for Low-Infrastructure Countries

Several studies have emphasized the core factors contributing to the success of National Research and Education Networks across Africa. Chief among these is the existence of a shared and participatory governance model, where the network is managed autonomously by the member institutions with a high level of transparency and accountability. Strong initial public investment often plays a pivotal role in launching these networks, but sustainability is achieved through a gradual diversification of funding sources, including service revenues, institutional contributions, and international support. The technical strength of the NREN depends on having qualified network engineers and maintaining continuous capacity-building initiatives. Regional cooperation is another key component, with alliances such as UbuntuNet Alliance, WACREN, and ASREN facilitating access to global research infrastructures, training opportunities, and collaborative projects [23]. Most successful NRENs have been developed following a phased roadmap, typically beginning with the establishment of governance structures, followed by interconnection of institutions, deployment of advanced services, and eventual integration into international scientific and academic networks [24]. Despite these successes, several African countries continue to face obstacles in building robust NRENs. Common challenges include the absence of coherent national policies on digital education and research infrastructure, insufficient coordination among government agencies and academic stakeholders, and the lack of critical technical infrastructure such as fiber-optic backbones, data centers, and Internet Exchange Points (IXPs). Furthermore, limited inter-university collaboration and a lack of a research-oriented digital culture continue to hinder progress.

2.4 Towards a Guinean Strategy

Guinea has several promising assets that could support the establishment of a national research and education network. Projects like Univ-Connect, led by the National Agency for the Digitalization of Higher Education (ANSUTEN), demonstrate a commitment to improving university connectivity through fiber-optic infrastructure. The country also benefits from a growing pool of motivated academic professionals and a political climate increasingly favorable to digital transformation in education. However, in the absence of a structured institutional framework, these efforts remain fragmented and insufficient to bring about systemic change. Drawing on the successful experiences of countries such as South Africa, Kenya, and Mozambique, Guinea has the opportunity to establish a Guinean Research and Education Network (GRERN) founded on strong institutional collaboration, strategic state leadership, and active engagement in regional initiatives like WACREN. By aligning technical, institutional, and financial resources within a coherent roadmap, Guinea can build a resilient and inclusive digital infrastructure that connects its universities and research centers, enhances their scientific output, and enables full integration into the global knowledge economy.

3. DIAGNOSTIC PHASE

3.1 Mapping Existing Resources

The diagnostic phase constitutes a critical preparatory step prior to the implementation of the Guinean Research and Education Network, as it provides an objective assessment of the existing technological, organizational, and human resource landscape. This phase aims to ensure that the proposed interconnection strategy is both technically feasible and institutionally realistic. Data were collected through institutional surveys, interviews with ICT managers, and on-site infrastructure assessments across a representative sample of public and private universities, covering urban and regional campuses.

The mapping of existing resources represents the first operational component of this diagnostic phase. It focuses on three main dimensions: connectivity, ICT equipment, and human resources. With regard to connectivity, the assessment reveals strong disparities between institutions and regions. Approximately 20–30% of universities, mainly located in Conakry and major regional capitals, benefit from partial fiber-optic connectivity through the national backbone managed by the National Backbone Management and Operations Company (SOGEB). These institutions typically have access to bandwidths ranging from 50 to 100 Mbps, with average latencies below 30 ms. In contrast, the majority of universities, particularly in remote regions, rely on 4G or satellite links offering less than 10 Mbps and experiencing latencies exceeding 100 ms, significantly limiting the use of bandwidth-intensive academic applications. Furthermore, despite Guinea's eligibility to join regional and international research and education networks such as WACREN, GÉANT, or UbuntuNet, none of the surveyed institutions currently maintain active interconnections with these networks.

In terms of ICT equipment, the results indicate that most universities possess only basic computing infrastructure. Approximately 60–70% of institutions host at least one local server supporting services such as learning management systems (e.g., Moodle) or internal administrative databases. However, these servers are generally non-redundant, non-virtualized, and lack backup and disaster recovery mechanisms. Core networking equipment, including routers, switches, and Wi-Fi access points, is present in most campuses, but is often undersized and unsuitable for large-scale interconnection or advanced network services. Dedicated videoconferencing facilities are limited to a small number of institutions, primarily in Conakry, and are usually the result of isolated donor-funded initiatives rather than a coordinated national strategy. Additionally, centralized tools for network monitoring, performance analysis, and security management are largely absent across institutions.

The assessment of human resources further highlights structural constraints. On average, universities employ one to three ICT technicians, often responsible for multiple roles ranging from network administration to user support and system maintenance. Qualified network engineers with expertise in routing, cybersecurity, and large-scale infrastructure management are heavily concentrated in the capital, resulting in limited local capacity in regional campuses. Less than 20% of institutions report having staff with internationally recognized ICT certifications, underscoring the

need for continuous capacity building and structured training programs. These findings emphasize that the success of a national academic network will depend not only on infrastructure deployment but also on strengthening institutional skills and governance mechanisms.

Overall, the mapping of existing resources reveals significant gaps between current capabilities and the requirements of a high-performance research and education network. These results directly inform the proposed NREN architecture by highlighting the necessity of a hierarchical and hybrid connectivity model, centralized network management, and a strong emphasis on capacity building and sustainability

3.2 Mapping of Stakeholders in Guinea

State partners also play a crucial role, particularly in regulation, strategic planning, and technical and financial support for the project. Key institutions include the Ministry of Higher Education, Scientific Research and Innovation (MESRSI), the Ministry of Posts, Telecommunications and Digital Economy (MPTEN), the Ministry of Economy and Finance (MEF), the National Agency for Information Systems Security (ANSSI), the National Agency for Information Society and Digital Technology (ANSI), and the National Backbone Management and Operations Company (SOGEB). These entities contribute to fiber-optic infrastructure management, cybersecurity, digital infrastructure development, and the coordination of major structural projects. Telecom operators and Internet Service Providers (ISPs) are also essential players in providing reliable and high-performance connectivity. Among them, Orange Guinea stands out for its wide national coverage and tailored offers for institutions, while MTN Guinea (formerly Areeba), Cellcom/Telecel Guinea, and SkyVision are considered potential technical partners for setting up dedicated links. The Guinea of Large Bande (GUILAB), which manages the ACE (submarine cable landing station), is a strategic gateway for international bandwidth, while SOGEB, as an infrastructure operator, oversees the national fiber-optic backbone. Finally, support from international organizations and development partners is vital to the project's success both financially and technically. The World Bank is involved through initiatives such as WARDIP and higher education development programs; the African Union supports digital transformation in education [25] [26]; UNESCO assists with ICT integration policies in higher education; and regional structures such as WACREN and UbuntuNet Alliance facilitate the interconnection of African NRENs with the global GÉANT network. Other actors such as GIZ (German Cooperation) and the International Organization of the Francophonie (OIF) provide significant support in capacity building, curriculum development, and the advancement of digital education and scientific research.

3.3 Proposed Infrastructure and Architecture for the GREN

The establishment of the GREN requires a robust, scalable technical architecture tailored to the realities of Guinea's geographic and institutional landscape. The goal is to build a national inter-university backbone network based on proven technologies and open standards, while ensuring security, redundancy, and high availability of digital services.

3.4 Infrastructure Components

The infrastructure of the GREN is built on a hierarchical and interconnected architecture. At its core is the central national node, or Network Operations Center (NOC), ideally located in a leading university such as Gamal Abdel Nasser University in Conakry. This center hosts the backbone of the network, including core routers, firewalls, a network monitoring system, and critical services such as a federated identity server (eduID), an eduroam portal (international academic Wi-Fi), DNS, email, and cache servers, an academic cloud platform, and a national data center for hosting research data. The NOC is connected to three to four regional Points of Presence (PoPs), strategically positioned in cities such as Labé, Kankan, N'Zérékoré, and Kindia, using fiber-optic or IP/MPLS links. These regional hubs help distribute traffic, reduce latency, and host local services such as Moodle and Single Sign-On (SSO). At the local level, each public university will operate a modern campus network that includes core and access switches, Wi-Fi access points, an identity management system, and fiber-optic interconnection to its designated regional PoP. The entire infrastructure is nationally interconnected through ANSUTEN initiatives (e.g., the Univ-Connect project), leveraging existing national fiber-optic networks. International connectivity is ensured through a link with WACREN, either via an Internet Exchange Point (IXP) in Conakry or through regional partners such as GÉANT or the UbuntuNet Alliance{Citation}, providing access to global scientific and academic resources.

3.5 Recommended Technologies and Implementation Conditions.

To ensure performance, security, and interoperability, the Guinean Research and Education Network (GREN) should adopt BGP for external routing with WACREN and OSPF for internal network management. Security will rely on UTM firewalls, site-to-site VPNs, and federated authentication using SAML and RADIUS. Network monitoring tools like Zabbix, Nagios, or prometheus are recommended, along with key services such as eduID, eduroam, and collaboration platforms for videoconferencing, file sharing, and messaging. The infrastructure will also support digital resources including MOOC hosting, research repositories, and thesis archives. Implementation requires a strategic partnership with ANSUTEN for fiber access, the creation of an Academic Interest Group (AIG-GREN) led by universities, and the mobilization of international funding (e.g., World Bank, African Union). Deployment will follow a phased approach: regional interconnection of pilot universities (Conakry, Labé, Kankan), national rollout to all public institutions, and eventual integration with global networks.

4. METHODOLOGY

4.1 General Approach

This study adopts a mixed-methods, exploratory, and design-oriented research approach to define an optimal architecture for the Guinean Research and Education Network (GREN). The objective is to support evidence-based decision-making for the development of a national digital infrastructure capable of interconnecting universities and research institutions in Guinea while ensuring performance, sustainability, and inclusiveness. Given the heterogeneous technological landscape, limited financial resources, and evolving institutional framework of the country, a multi-dimensional methodology integrating technical, organizational, economic, and regulatory aspects was required.

The research was conducted in four sequential and interrelated phases: (i) documentary analysis and benchmarking, (ii) field data collection, (iii) analytical assessment and synthesis, and (iv) technical and economic design. This phased approach ensured methodological rigor while allowing iterative refinement of the proposed network architecture.

The first phase consisted of a systematic literature review and comparative analysis of National Research and Education Network (NREN) models at international and regional levels. Policy documents, technical reports, and peer-reviewed publications related to established NRENs such as KENET (Kenya), RENATER (France), and SANReN (South Africa) were analyzed to identify best practices in governance models, network topology, service portfolios, funding mechanisms, and interconnection strategies. Special attention was paid to African and developing-country contexts to ensure relevance and transferability to Guinea. In parallel, regional initiatives such as WACREN were examined to assess opportunities for international academic interconnection and bandwidth optimization.

The second phase focused on empirical data collection within the Guinean higher education and research ecosystem. Data were gathered from multiple sources to ensure triangulation. Institutional data were collected from national regulatory and policy bodies, including the Autorité de Régulation des Postes et Télécommunications (ARPT), the Ministry of Higher Education, Scientific Research and Innovation (MESRSI), and the Ministry of Digital Economy. These data included information on national fiber backbone deployment, regulatory frameworks, connectivity costs, and existing ICT policies. In addition, field surveys were conducted across selected public and private universities and research centers to assess local network infrastructure, available bandwidth, connectivity technologies, equipment status, and ICT service usage. Semi-structured interviews were also carried out with key stakeholders, including university ICT managers, academic administrators, policymakers, and technical experts, to capture qualitative insights on operational challenges, institutional needs, and readiness for a shared national network.

The third phase involved the analysis and synthesis of collected data. Qualitative data from interviews were analyzed using thematic analysis to identify recurring patterns related to infrastructure gaps, governance issues, and capacity constraints. Quantitative indicators such as bandwidth availability, network reliability, connectivity costs, and geographic coverage were comparatively analyzed across institutions. The results were consolidated into an analytical framework highlighting structural strengths, weaknesses, opportunities, and threats, which directly informed the strategic and technical decisions in subsequent phases.

The final phase consisted of the design and modeling of the GREN architecture, integrating findings from the previous phases. A multi-criteria decision-making logic was applied to evaluate technical options based on performance, scalability, resilience, cost-efficiency, and alignment with national development priorities. This phase resulted in the proposal of a hybrid connectivity model, a layered network architecture, and a preliminary economic framework combining public funding, institutional contributions, and international partnerships.

Overall, this methodology ensures a context-aware, evidence-based, and reproducible framework for the design of a National Research and Education Network in Guinea. The approach can be adapted to other developing countries facing similar infrastructural and institutional challenges, thereby contributing to broader discussions on digital transformation in higher education and research.

4.2 SWOT Analysis of the University Interconnection Sector in Guinea

A Strengths Weaknesses Opportunities Threats (SWOT) analysis was conducted as a structured decision-support tool to assess Guinea's readiness for the implementation of a nationwide academic and research interconnection network. The objective of this analysis was not only to describe the current situation but also to systematically identify internal and external factors influencing the feasibility, sustainability, and scalability of the proposed Guinean Research and Education Network (GREN). The SWOT framework was selected for its relevance in strategic infrastructure planning, particularly in contexts characterized by institutional complexity and uneven technological development.

The SWOT analysis was built using a triangulated data approach. Internal factors (strengths and weaknesses) were derived primarily from field surveys conducted within public and private universities and research institutions, complemented by semi-structured interviews with ICT managers, academic administrators, and technical staff. External factors (opportunities and threats) were identified through the analysis of national policy documents, regulatory frameworks, donor programs, and regional and international NREN initiatives. This combination of qualitative and quantitative sources ensured the reliability and contextual relevance of the identified factors.

To enhance analytical rigor, the identified SWOT elements were screened and prioritized according to predefined criteria, including their potential impact on network deployment, operational sustainability, and long-term scalability. Factors that emerged consistently across multiple data sources were retained as dominant drivers or constraints. The resulting SWOT matrix therefore reflects not only isolated observations but converging evidence from institutional, technical, and policy-level perspectives.

The analysis reveals several structural strengths favorable to the development of GREN. These include the geographically balanced distribution of public universities and higher education institutions across major regions (Conakry, Labé, Kankan, Kindia, N'Zérékoré, Boké, and Mamou), as well as the presence of active research centers in strategic sectors such as health, agriculture, environment, and mining. The progressive deployment of the national fiber-optic backbone, managed by SOGEB, constitutes a critical enabling infrastructure, particularly in urban and peri-urban areas. These assets are reinforced by strong political commitment to higher education modernization and digital transformation, supported by national strategies and partnerships with international donors such as the World Bank. In addition, the availability of a growing pool of young ICT professionals, trained both domestically and abroad, represents a valuable human resource for network deployment and operation.

Conversely, the analysis highlights significant internal weaknesses that constrain effective interconnection. Notable disparities exist in terms of network infrastructure, equipment quality, and connectivity capacity among institutions. While some universities such as Université Gamal Abdel Nasser de Conakry (UGANC) and Université Sonfonia benefit from relatively better connectivity, many regional and rural campuses remain underserved and rely heavily on costly and unreliable VSAT solutions. Existing networking equipment is often outdated, lacks redundancy, and is insufficiently secured, exposing institutions to operational and cybersecurity risks. Furthermore, the limited availability of qualified network

engineers and system administrators results in dependence on external service providers or overburdened internal staff. The absence of a unified digital governance framework across institutions further limits service sharing, interoperability, and standardization efforts.

Despite these constraints, the SWOT analysis identifies substantial external opportunities. The national fiber backbone provides a foundational infrastructure for interconnecting campuses across regions. Prospective membership in the West and Central African Research and Education Network (WACREN) offers the potential for access to high-capacity, cost-effective academic bandwidth and integration into global research and education networks. International development partners including the World Bank, UNESCO, the "Organisation internationale de la Francophonie (OIF)", and GIZ have demonstrated strong interest in supporting digital transformation initiatives in higher education. Moreover, partnerships with established international NRENs such as RENATER, GÉANT, and UbuntuNet present opportunities for knowledge transfer, capacity building, and technical interoperability. The presence of operational NRENs in neighboring countries (e.g., Senegal, Benin, and Côte d'Ivoire) further strengthens regional collaboration prospects.

Finally, the analysis identifies critical external threats that could undermine the successful implementation of GREN if not adequately addressed. These include administrative instability, frequent leadership changes, and institutional delays that may affect project continuity and governance. The persistently high cost of bandwidth in West Africa, particularly outside capital cities, poses a challenge to equitable nationwide deployment. In addition, the absence of a comprehensive national cybersecurity strategy for academic networks increases exposure to cyberattacks, data breaches, and service disruptions. Weak inter-ministerial coordination and fragmented institutional responsibilities risk duplication of efforts and incoherent implementation. Lastly, limited digital literacy and low adoption of collaborative digital tools in some academic environments may reduce the effective utilization and impact of the proposed network.

Overall, the SWOT analysis plays a central methodological role in this study by informing the architectural design, governance model, and phased deployment strategy of GREN. By explicitly linking contextual constraints and opportunities to technical and organizational choices, the SWOT framework contributes to a coherent, realistic, and sustainable national interconnection strategy.

4.3 Design Phase

The design phase represents a critical methodological step in the establishment of the Guinean National Research and Education Network (GREN), translating diagnostic findings into a technically and economically viable network model. This phase aims to define a robust technical architecture, select appropriate connectivity technologies, and develop a preliminary cost and financing framework. It follows a structured, evidence-based approach to ensure that the proposed network is scalable, resilient, secure, and aligned with both national constraints and international NREN standards.

The design process was conducted using a multi-criteria decision-making framework, integrating technical performance, geographic feasibility, cost-efficiency, institutional capacity, and long-term sustainability. Inputs from the diagnostic and SWOT analyses were systematically mapped to design requirements, ensuring coherence between identified needs, constraints, and proposed solutions.

4.4 Proposed Technical Architecture

The proposed GREN architecture was developed following a layered and hierarchical network design methodology, commonly adopted in large-scale academic and research networks. The architecture is structured into three logical layers: a national core (backbone) layer, a regional aggregation layer, and an institutional access layer. This separation enables scalability, simplified management, and fault isolation.

At the core layer, a national academic backbone is proposed, consisting of high-capacity links interconnecting major universities and national research centers. Strategic national exchange points will serve as interconnection hubs to regional and international research networks, enabling seamless integration with WACREN and, indirectly, with global infrastructures such as GÉANT. Core links were dimensioned based on projected traffic growth, with the objective of ensuring sufficient bandwidth headroom and minimizing congestion.

The regional aggregation layer comprises regional access nodes deployed in key academic hubs, including Conakry, Labé, Kindia, Kankan, and N'Zérékoré. These nodes aggregate traffic from nearby institutions and provide redundancy paths to the national backbone. Their locations were selected based on institutional density, geographic accessibility, and proximity to existing fiber infrastructure. This topology reduces long-haul dependencies and enhances network resilience.

The institutional access layer connects individual universities and research centers to the regional nodes. Access technologies were selected using a hybrid connectivity model, reflecting Guinea's heterogeneous geographic and infrastructural conditions. Optical fiber was prioritized for institutions located along the national backbone, leveraging existing infrastructure managed by public entities and operators such as SOGEB. For secondary or peri-urban institutions not yet connected by fiber, high-capacity wireless solutions (radio links and microwave transmissions) were evaluated as transitional options, offering faster deployment at lower initial cost. In highly remote regions, including parts of Upper Niger and Forest Guinea, satellite connectivity was considered as a last-resort solution to guarantee minimal academic connectivity, despite its higher latency and operational cost.

From a protocol and service perspective, the architecture incorporates IPv6 for long-term address scalability, BGP for inter-domain routing and redundancy, and MPLS for traffic engineering and quality-of-service enforcement. Security and trust are addressed through the integration of shared firewalls, intrusion detection and prevention systems (IDS/IPS), and inter-institutional virtual private networks (VPNs). In addition, a centralized identity and access management system supports federated services such as eduroam, secure authentication, and controlled access to shared resources. These architectural choices were guided by best practices observed in established NRENs and validated against local operational capacities.

4.5 Cost Estimation and Potential Economic Models

The economic dimension of the design phase involved a preliminary cost estimation and financial modeling exercise, aimed at assessing the feasibility and sustainability of GREN. Costs were categorized into capital expenditures (CAPEX) and operational expenditures (OPEX), following standard infrastructure planning methodologies.

CAPEX estimates include investments in core and edge network equipment (routers, switches, servers), physical infrastructure (fiber deployment, towers, civil works), data center facilities, and network management and collaboration platforms. OPEX estimates encompass recurring costs such as bandwidth leasing, infrastructure maintenance, energy consumption, cybersecurity operations, software licensing, and human resources, including network engineers, system administrators, and training personnel. Cost assumptions were informed by benchmarks from comparable African NREN deployments and adjusted to reflect local market conditions and regulatory constraints.

To address financial sustainability, multiple economic and governance models were evaluated. These include a predominantly public funding model led by relevant ministries, a public–private partnership model involving national telecom operators, and a hybrid cost-sharing model combining public funding, institutional membership fees, and international donor support. Contributions from member institutions were envisioned to be progressive and proportional to institutional size and bandwidth consumption, ensuring equity and inclusiveness.

The selected economic framework is embedded within a phased implementation master plan, allowing incremental investment aligned with available resources and evolving demand. This approach reduces upfront financial risk while enabling gradual expansion of services and coverage. Beyond cost considerations, GREN is conceived as a nationally co-constructed initiative that strengthens digital resilience, fosters inter-institutional collaboration, and promotes regional integration. Its design draws on lessons learned from existing NRENs and aligns with global priorities for digital transformation in higher education and research.

The figure (**Figure** 1) presents the organization of the diagnostic phase in the project to interconnect Guinean universities (GREN). It shows that the preliminary analysis is structured around three complementary axes. The first focuses on identifying existing resources, including connectivity, equipment, and available human resources within the institutions. The second axis consists of mapping the actors involved, such as state partners, telecom operators, Internet service providers, and other stakeholders. Finally, the SWOT analysis evaluates the sector's strengths, weaknesses, opportunities, and threats. Together, these elements provide a clear understanding of the initial situation, which is essential for guiding the design of the GREN network.

Figure 2, represent interconnection diagram of public universities in Guinea through a national digital infrastructure. This diagram illustrates the proposed topology for the Guinean Research and Education Network (GREN), linking the main public higher education and research institutions, including the University of Labé (UL), Julius Nyerere University of Kankan (UJNK), the University of N'Zérékoré (UZ), and Gamal Abdel Nasser University of Conakry (UGANC), among others. The routers represent regional Points of Presence (PoPs) that provide connectivity via a fiber-optic or IP/MPLS network. The goal of this architecture is to enable resource sharing, access to collaborative services, and connection to international scientific networks such as WACREN and GÉANT.

An initial assessment of current connectivity across Guinean universities reveals significant disparities in infrastructure and bandwidth availability, as summarized in Table 1.

Table 1. Current Infrastructure and Connectivity

Institution	Type	Bandwidth (Mbps)	Latency (ms)	Availability (%)
UGANC	Fiber Optic	8	180	95
UK	4G/Satellite	5	120	70
UL	Satellite	3	150	65
UNJK	4G	8	100	75
UZ	Satellite	2	180	60

Table 2 presents the estimated bandwidth requirements for critical academic applications, highlighting the gap between current capabilities and institutional needs.

Table 2: Institutional Bandwidth Needs for Critical Applications

Institution	E-learning	Access to Scientific Resources	Computing / HPC	Estimated Volume (Mbps)
UGANC	40	30	20	90
UK	10	15	5	30
UL	5	10	5	20
UNJK	15	10	10	35
UZ	5	5	2	12

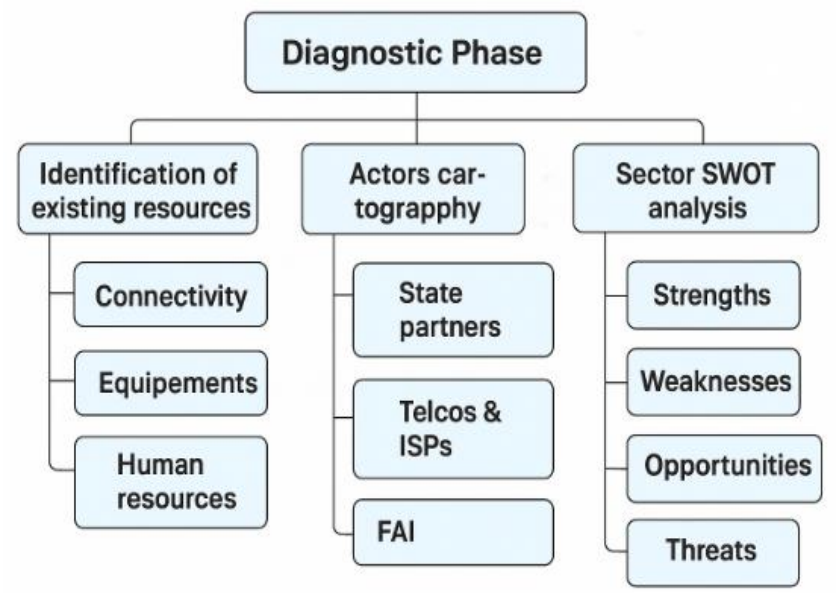

Figure 1: Diagnostic Phase

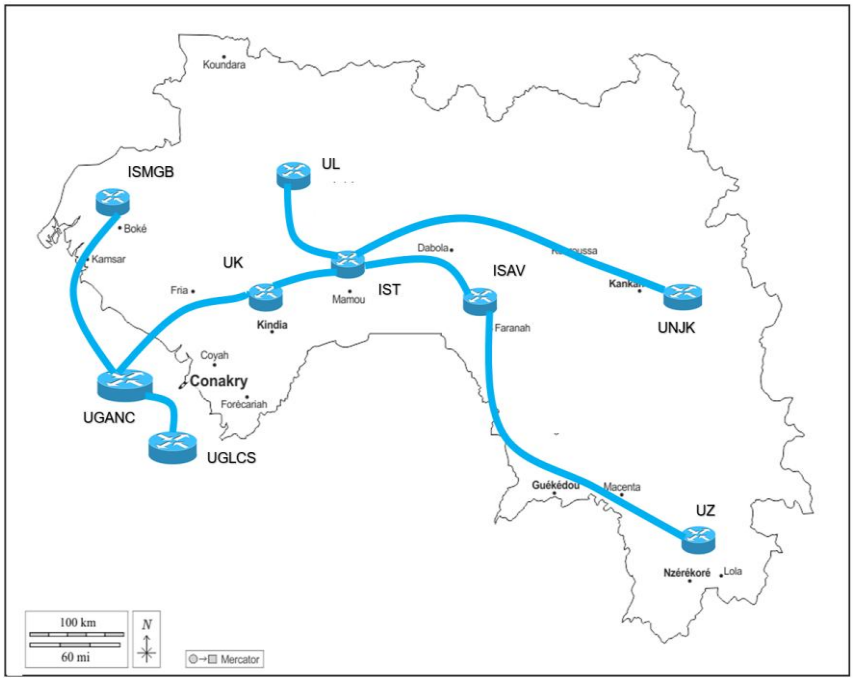

Figure 2: Interconnection Diagram of Public Universities in Guinea through a National Digital Network

A comparative overview of the current network architecture and the proposed NREN is presented in Table 3, illustrating expected performance enhancements

Table 3: Comparative Table of Network Architectures

Criterion	**Current Architecture**	**Proposed NREN**	**Expected Improvement**
Average Bandwidth	5–10 Mbps	50–100 Mbps (urban), 5–10 Mbps (rural)	5–10
Average Latency	100–180 ms	15–25 ms (urban), 50–80 ms (rural)	70–80%
Redundancy	Low	High (dual fiber, alternative routes)	Significant
Integrated Services	Limited	VPN, eduroam, collaborative platforms	Academic quality
National Coverage	Partial	Nationwide	100% of universities

Table 4 summarizes the estimated costs of implementing the NREN, highlighting the major investment areas and their share of the total budget

Table 4: Techno-Economic Table (Estimated Costs)

Budget Item	Estimated Cost (USD)	% of Total Budget
Core Network Equipment	3,500,000	44%
Fiber Optic	2,500,000	31%
Campus Access Equipment	1,500,000	19%
Software & Services	500,000	6%
Training & Gouvernance	250,000	3%
Total	**8,250,000**	100%

Finally, Table 5 illustrates the expected gains in performance, availability, and academic collaboration following the implementation of the NREN

Table 5: Expected Gains (Performance and Impact)

Indicator	Current Situation	After NREN	Gain
Average Bandwidth	5–10 Mbps	50–100 Mbps	5–10
Average Latency	120 ms	15–25 ms	80%
Network Availability	65–80%	95–99%	20–30%
Access to Academic Ressources	Limited	Unlimited	Significant
Inter-University Collaboration	Low	High	Significant

In order to enhance the robustness of the evaluation, multiple deployment scenarios were considered in order to reflect the heterogeneity of Guinean higher education institutions. Three representative scenarios were analyzed: (i) urban universities with access to the national fiber backbone, (ii) regional institutions using hybrid fiber and wireless connectivity, and (iii) remote campuses relying primarily on satellite links. For each scenario, key performance indicators such as available bandwidth, end-to-end latency, scalability, service availability, and estimated operational costs were evaluated. The results indicate that the proposed NREN architecture remains effective across all scenarios, with significant improvements in connectivity and service quality compared to existing configurations, while maintaining cost efficiency through hybrid access models. This scenario-based evaluation demonstrates the adaptability and resilience of the proposed architecture under diverse technical and geographical conditions.

5. RESULTS AND DISCUSSION

The feasibility study and structural analysis of a National Research and Education Network (NREN) in Guinea provide a comprehensive understanding of both technical and organizational requirements. The assessment of higher education institutions reveals that connectivity is highly uneven: while a few urban universities benefit from fiber-optic links with bandwidths between 50 and 100 Mbps, most institutions, especially in rural areas, rely on satellite or 4G connections offering less than 10 Mbps and high latency. Infrastructure limitations, including minimal redundancy, outdated equipment, and a lack of virtualized services, further restrict performance. In addition, qualified ICT personnel are concentrated in major cities, creating operational bottlenecks. These findings demonstrate the urgent need for a coordinated, high-performance, and secure academic network capable of supporting advanced applications such as distributed computing, access to scientific databases, and collaborative online learning.

The proposed technical architecture addresses these challenges through a hierarchical design consisting of a national core backbone, regional aggregation nodes, and institutional access layers, complemented by alternative connectivity solutions for remote campuses. Simulation results indicate that the core fiber-optic network, with links ranging from 10 to 40 Gbps between major cities, can accommodate projected traffic for the next five years. Regional aggregation points significantly reduce latency, from over 120 ms in remote connections to under 20 ms in urban campuses, while hybrid access technologies ensure minimum bandwidth of 5–10 Mbps nationwide. Integrated services such as federated authentication (eduroam), inter-institutional VPNs, and collaborative platforms enhance interoperability, security, and access to shared digital resources, creating the foundation for a national academic digital ecosystem.

From an economic perspective, techno-economic analyses suggest that initial investments, particularly for core network equipment and civil works, are substantial, estimated at USD 8–10 million. However, phased deployment, centralized management, and public-private partnerships can optimize costs and improve resource utilization. Operating expenses, projected at USD 0.8–1 million annually, could be reduced by approximately 25% through efficiency strategies, including shared services and pooled infrastructure. Comparisons with NRENs in neighboring countries indicate that leveraging existing government and telecom infrastructure allows Guinea to achieve comparable performance standards at a lower cost.

Equally important is governance: the study highlights that technological implementation alone is insufficient. Establishing an independent management body that brings together universities, relevant ministries, telecom operators, and international partners is critical to ensure sustainability, accountability, and effective coordination. Beyond technical and economic dimensions, the interconnection of universities represents a strategic lever for digital inclusion, capacity building, and enhancing Guinea's visibility in regional and international research networks. Overall, the results demonstrate that the GREN project is technically feasible, economically viable, and institutionally sustainable, provided that deployment follows a phased, evidence-based, and well-governed approach.

6. CONCLUSION

The establishment of a National Research and Education Network (NREN) in Guinea stands as a strategic priority to modernize higher education, enhance research capabilities, and promote digital inclusion. This study has demonstrated the feasibility of such an initiative by proposing a robust, scalable, and contextually appropriate technical architecture suited to

Guinea's geographic and economic realities. By leveraging existing infrastructure, adopting diverse access technologies, and applying blended financing models, it is possible to interconnect Guinean universities effectively both among themselves and with the global academic community. This interconnection should not be seen merely as an infrastructure project, but rather as a catalyst for pedagogical, scientific, and institutional transformation. Its success will depend on inclusive governance, strong political will, and active engagement from the academic sector. Looking ahead, several avenues can be pursued to support and strengthen the deployment of Guinea's NREN. These include starting with the interconnection of a limited number of pilot universities to test the proposed architecture, services, and governance mechanisms before scaling nationally; progressively implementing value-added services such as digital libraries, e-learning platforms, academic cloud services, and shared scientific computing environments; enhancing technical and organizational capacities through continuous training programs for network engineers, system administrators, and digital managers; integrating Guinea into continental initiatives such as WACREN and the UbuntuNet Alliance to benefit from experience-sharing, shared resources, and international funding opportunities; and establishing a monitoring and evaluation system to assess the NREN's impact on teaching quality, scientific output, and digital equity among institutions. The successful realization of this network will anchor Guinean universities firmly within the global movement toward open science, academic cooperation, and digital innovation.

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