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Breaking the Final Connectivity Barriers for Higher Education Institutions in Africa: The Next Steps and A Call to Action[1]

F F "Tusu" Tusubira, Lishan Adam, Ali Ndiwalana

Knowledge Consulting Ltd.
www.kcl.co.ug

1 *The authors acknowledge with thanks the World Bank Group (WBG) who granted permission to draw on data and analysis from a 2020 Feasibility Study for connecting all African universities to high-speed Internet (http://hdl.handle.net/10986/36042). This paper also draws extensively on earlier publications and data from the UbuntuNet Alliance, GÉANT Association, and the WBG.*

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Abbreviations

Term	Description
AAU	African Association of Universities
ACFTA	African Continental Free Trade Area
AfriNIC	African Internet Registry
ASREN	Arab States Research and Education Network
AUC	African Union Commission
BWC	Bandwidth Consortium
EUC	European Union Commission
GDP	Gross Domestic Product
HEI	High Education Institution
ICT	Information and Communications Technology
IRU	Indefeasible Right of Use
ISP	Internet Service Provider
IXP	Internet Exchange Point
LDC	Least Developed Country
Mbps	Megabits per second
NREN	National Research and Education Network
NSRC	Network Startup Resource Center
PHEA	Partnerships for Higher Education in Africa
RCIP	Regional Communications Infrastructure Project
REN	Research and Education Network
RREN	Regional Research and Education Network
SDG	Sustainable Development Goal
SPOC	Small Private Open Courses
Tbps	Terabits per second
TVET	Technical and Vocational Education and Training
UNESCO	United Nations Education Scientific and Cultural Organization
WACREN	West and Central African Research and Education Network
WBG	World Bank Group
Wi-Fi	Local area wireless computer networking technology

1. Introduction

During the late 90s, a growing wave of action started among African universities and research institutions, focusing on the need for global connectivity to provide access to especially journal databases and other online resources. Alongside this was the general continental move towards liberalisation of the telecommunications sector to introduce more competition and reach more people. The only option for regional and global connectivity at the time for most of Africa, was via satellite, and that at very prohibitive costs, translating to a current €25,000 per Mbps/month. This ignited the push for collaboration to increase negotiating power and to benefit from economies of scale. A Bandwidth Consortium (BWC) funded by the US-based Foundations' Partnership for Higher Education in Africa (PHEA) was among the first initiatives to aggregate the purchase of connectivity for higher education.[2] National Research and Education Networks (NRENS) and Regional Research and Education Networks (RRENs) started taking root in Africa. The International Development Research Centre and the Network Startup Resource Centre (NSRC)[3] played key roles in the initial funding, training, and popularisation of the Research and Education Network (REN) concept in the continent.[4]

Since then, a lot has been achieved, especially within the countries that were pioneers or early adapters to REN activity. The EU has provided tremendous funding support in the process, as did Dante and TERENA, now formally merged as GÉANT[5], through implementation, sharing experience, and training. NRENs from Europe, Internet2[6], and Red CLARA[7] also came into the picture as learning resources. Developments in Eastern and Southern Africa are a strong testimony to the value and impact of NRENs and RRENs, with large consumer universities now accessing national, regional and global connectivity via fibre at less than $20 per Mbps per month, and at the same time rapidly increasing institutional internal and external connectivity. Alongside this, a lot of progress has also made in the area of networking skills, creating a strong pool of engineers with frontline competence. NRENs in several of these countries stepped up and, working collaboratively with the private sector, extended connectivity reach outside campuses to enable continuity of learning and access to online resources during the COVID-19 lockdowns.

However, much more remains to be done for Africa to catch up and perform at the same level with the rest of the world. Major connectivity gaps still exist in most African countries. Broadband costs still have to go down to levels common around the world, and specifically responding to the African Union's "The Digital Transformation Strategy for Africa (2020 – 2030)"[8] which states that "By 2030 all our people should be digitally empowered and able to access safely and securely to at least (6 Mb/s) all the time where ever they live in the continent

2 https://www.fordfoundation.org/media/1760/2010-accomplishments-of-the-partnership-for-higher-education-in-africa.pdf
3 https://nsrc.org
4 https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/40485/128887.pdf
5 https://www.geant.org
6 https://internet2.edu
7 https://www.redclara.net/index.php/en/
8 https://au.int/sites/default/files/documents/38507-doc-dts-english.pdf

at an affordable price of no more than (1cts USD per Mb)….". Achieving this will call for deeper appreciation by African governments of NRENs' as a great opportunity for national development.

The underlying theme of this paper is the critical need for high-quality broadband connectivity to higher education institutions[9] (HEIs) in Africa, along with inclusion of the lower levels of education, and the central role that National Research and Education Networks (NRENs) and Regional Research and Education Networks (RRENs) have to play as enabling vehicles for this to be achieved. The objective is to deepen awareness and to mobilise a coordinated effort among African governments and development partners to address the remaining barriers.

Action is particularly needed in addressing the following major areas where large gaps exist over most of the African continent:

i. Creating policy and regulatory environments (or eliminating barriers therein) to enable growth in competitive national and regional connectivity environments. Competitive development is required in coastal and inland marine fibre landing points, national and transnational terrestrial fibre, and carrier-neutral data centres. The development of internet exchange points is a key requirement in keeping local traffic local in any country and its sub-divisions.

ii. Addressing "last mile" and "last inch" access through the development of sufficient, resilient, and scalable campus networks as well as their connection to high-capacity national backbones; and ensuring, through different schemes, individual ownership of laptops by all students and staff in HEIs.

iii. Addressing awareness and knowledge gaps concerning the major positive impact of high-quality broadband on the many ways in which HEIs contribute to national development; the significant differences between REN and commercial data connectivity; and the need for governments to support the growth of NRENs as one of the key national development strategies.

iv. Engaging development partners to implement massive coordinated interventions that will ensure accelerated and sustainable change.

All these require ownership and investment by national governments and championing by HEIs so that development partner support has strong foundations to build on.

9 *Higher Education, also known as Tertiary Education in some countries, is used here to refer to all post-secondary education, including both public and private universities, colleges, technical training institutes, and vocational schools* https://www.worldbank.org/en/topic/tertiaryeducation

2. Aspirations, and the Reality

Vision:

> *"An African continent where all higher education institutions achieve global parity in intellectual output and development impact through access to, and exploitation of broadband connectivity at capacities, quality, and costs comparable to the rest of the world."*

It should be noted that parity in connectivity and intellectual property output as a stage for contribution to development has been the aspiration of Africa NRENs from their pioneering days[10]. The sufficiency and affordability of broadband can also be seized as opportunities to improve learning and research outcomes, as well as employability in the context of the fourth industrial revolution[11].

What is the current connectivity reality? The African Higher Education sector consists of about 1,250 Universities and 6,000 technical level institutions. Among them, they have a student and staff population of about 16 million. Table 1 gives examples of bandwidth to the largest institutions in selected African countries, and Table 2 gives the optimal requirement per student for HEI level connectivity. Most universities currently provide less than 100 Mbps per 1000 students, which is far below what is desirable even if usage diversity (in that not everyone would be doing everything at once or simultaneously) is factored in.

Table 1: Examples of bandwidth to the largest universities in selected African countries

University	Country	Student enrolment (2020)	Bandwidth procured (Mbps)	Bandwidth/1000 Students (Mbps)
Makerere University	Uganda	36,477	2,020	55.4
Universidade Eduardo Mondlane	Mozambique	44,129	1,260	28.6
University Ouagadougou I Professeur Joseph Ki-Zerbo	Burkina Faso	70,000	34	0.5
Nairobi University	Kenya	84,000	3,000	35.7
University of Somalia	Somalia	9,000	70	7.8
Université Félix Houphouët-Boigny	Côte d'Ivoire	50,000	1,000	20.0

Source: KCL

10 *See, e.g., https://www.idrc.ca/en/project/consolidating-african-research-and-education-networking-corena-phase-i; or UbuntuNet Alliance archives*

11 *https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/*

Table 2: Optimal bandwidth requirement for teaching, learning and research

Teaching, learning and research needs	Optimal bandwidth per student
Access to Open Educational Resources	1 Mbps
Learning Management System, Moodle, Canvas	1 Mbps
Online Public Access Catalogue, digital library access	500 Kbps
Video streaming	5 Mbps
Remote Instruction	1 Mbps
Video Conferencing	1.5 Mbps
Large files download	100 Mbps
Open science – access to lab and instruments	100 Mbps

Source: Various

Table 3 gives examples from around the world of connectivity capacity to institutions of different sizes. The categorisation SML where used refers to Small campuses (less than 5,000 students), Medium campuses (5,000 – 15,000 students), and Large campuses (more than 15,000 students). It is evident that despite the progress that has been made in African countries where NRENs have been active, a big gap still remains for Africa to be at par with the rest of the world. There are some exceptions to this, especially in South Africa and Egypt, but this does not change the general picture.

Table 3: Bandwidth Comparison for Higher Education around the world

NREN/Country	Details of what is available	Remarks
KENET (Kenya)	Normalised designations: 40 Mbps @1,000 students. Projection: 100 – 200Mbps @1,000 students in five years	2020 data from KENET
TENET (South Africa)	Uses port sizes that ensure normal usage on campuses is does not exceed 50% of the available capacity	2020 data from TENET Defines broadband as "sufficient bandwidth to be able to use the prevailing applications of the day."[12]
RNP (Brazil) (Current)	They use the SML categorisation. Ranges from 100Mbps for small institutions to 3 – 100 Gbps for large ones.	2020 data from RNP
Red CEDIA (Ecuador)	They use the SML categorisation. Ranges from 1Gbps for small to 5Gbps for large.	2020 data from Red CEDIA
CENIC (California)	They use the SML categorisation. Ranges from 1 – 10Gbps for small institutions to 100 – 200Gbps for large ones. Projection: 1 Gbps for small and >400Gbps for large in 3 years	2020 data from CENIC The CEO stated that "Rapid technology evolution makes prediction of capacity beyond 3 years tough"

12 *Discussions with Duncan Greaves, CEO of TENET, Republic of South Africa*

NREN/Country	Details of what is available	Remarks
AARNet (Australia)	Ranges from 10 to 100 Gbps	2018 TEIN Compendium
SingAREN (Singapore)	Ranges from 1 to 10 Gbps	2018 TEIN Compendium
GRENA, Georgia (Small GÉANT member NREN)	Using the SML categorisation: Small - approx. 100 Mbps; Medium, 100 - 300 Mbps; and Large, 500 - 1000 Mbps	2020 data from GRENA. "We made a very rough estimation of GRENA international traffic increase during next five years, and it was approximately 100%."
AMRES, Serbia (Medium GÉANT member NREN)	Dark fibre technology is used for Universities (e.g., faculties, institutes and the biggest schools). Dark fibre locations are connected by 1Gbps and 10Gbps throughput.	2020 data from the AMRES. "We typically make our estimations with a traffic increase factor of 25% per year. It means that for the 5 years, we expect a threefold traffic increase."
DFN, Germany (Large GÉANT member NREN)	20Gbps and 10Gbps were typical for universities and research institutions, respectively	Based on the 2018 GÉANT Compendium.

Source: KCL

Table 4 gives the aspirational progressive connectivity targets based on benchmarking and extensive engagement with Africa NRENs as well as key supporters within and outside Africa. Next-generation networking technologies[13] are an opportunity to make these realistic aspirations targets.

Table 4: Recommended Progressive Bandwidth Targets for African Universities and TVETs

Year	Minimum Bandwidth	Remarks
2021 (target minimum)	≥ 0.2 Gbps @1,000	Translates to 1Gbps minimum for a campus of 5,000; and 10 Gbps for a campus of 50,000.
2020 - 2025	≥ 2 Gbps @1,000	Translates to 10 Gbps minimum for a campus of 5,000; and 100 Gbps for a campus of 50,000.
2025 - 2030	≥ 20 Gbps @1,000	Translates to 100 Gbps minimum for a campus of 5,000; and 1 Tbps for a campus of 50,000. Actual size for any campus to be based on the TENET approach: "sufficient bandwidth to be able to use the prevailing applications of the day" with port sizes twice the normal usage.

Source: KCL

13 https://www.mordorintelligence.com/industry-reports/next-generation-network-market

3. What, and Why NRENs?[14]

NRENs have played a major role in what has been achieved in connectivity to HEIs in Africa during the last 20 years. This section delves into the What and Why of NRENs and highlights the many other development opportunities they bring, especially to developing countries.

The main purpose of NRENs is to provide access and related facilities that enable research and education *collaboration* among researchers, educators, and special interest groups that exist among the different campuses of different universities and research institutes in the country. It should be noted that *"collaboration"* is both a trait and a critical success factor of the knowledge society. Research and education networks, both national and regional, are crucial links in the connectivity value chain. There is, however, much more to NRENs than simply supporting the higher education sector: NRENs are also a key driver and enabler for national development. They specifically support most of the Sustainable Development Goals, especially those concerning quality education (SDG4), decent work and economic growth (SDG 8), and Industry and Innovation (SDG 9).

3.1 NRENs and the Higher Education Sector

The unique role of NRENs at the national, regional, and global levels is built on several key pillars:

i. **Collaboration:** developing and implementing collaboration platforms and opportunities that enable individual researchers, research communities, or communities of educators to work together at the national, regional, or global level. Collaboration for African HEIs both regionally and globally is now more important than ever before. The technologies, opportunities, and challenges driving the fourth industrial revolution are global. It is imperative for HEIs—students, faculty, and management—to be in constant touch with all these and get involved, and indeed participate in leadership. This is the only way African HEIs can ensure that curricula, pedagogy, and research are relevant and will generate the human resource and other products that will make and keep Africa competitive. To do otherwise is to condemn African nations once again to a spectator role in global development.

ii. **Access to research assets:** developing countries face a challenge of financial capacity, human resource capacity, and utilisation capacity to establish and sustain major research assets like high-performance supercomputers or advanced scientific instrumentation. Research and Education networks provide the opportunity and quality of connectivity to access such assets through bilateral or multilateral arrangements, along with the associated collaboration opportunities, levelling the ground for researchers from developing countries. Indeed, NRENs are included as a

14 *See also: https://casefornrens.geant.org/Pages/Home.aspx and https://openknowledge.worldbank.org/handle/10986/26258*

key requirement for universities in the least developed countries (LDCs) to access initiatives like the proposed United Nations Technology Bank[15].

iii. **Connectivity:** all users should have sufficient anytime, anywhere access to the different online resources as well as collaboration platforms and opportunities around the world. It is the aspect of connectivity that makes many governments look at NRENs simply as connectivity providers. From this perspective, the private sector connectivity providers in developing countries also tend to see NRENs as competitors. There is, however, a major difference between REN and commercial connectivity. REN networks are dimensioned to be responsive to research and education needs, which are often characterised by intermittent very high bandwidth demands. Such networks, therefore, run at 50 – 60% of available capacity during normal operation.

On the other hand, commercial networks are operated close to full capacity, and therefore cannot respond to the demands of research and education. The ethos of operation of RENs is also different from that of commercial networks: *"While commercial ISPs are characterised by fierce competition; R&E networks typically are publicly funded not-for-profit organisations that thrive on collaboration. This collaborative spirit is at the heart of the global R&E network community, empowering research and education across the globe."*[16].

From another source: *"As the scientific community pushes the boundaries of our knowledge, researchers rely on dedicated data communications networks to provide greater speeds, timely delivery, seamless global reach and a very high level of resilience."*[17] Therefore, the nature and tailored capability of the connectivity distinguishes the dedicated Research and Education connectivity from the commercial connectivity. To illustrate the difference: tests conducted using large file transfers (100 Terabytes) on NREN networks and two commercial ISPs – all without any advance notifications – resulted in transfer durations of 1.4 days for the NREN links and 7.6 and 119.3 days via two different commercial ISPs[18].

One unique connectivity aspect of research and education networks is global roaming through eduroam (education roaming). *"This is the secure, world-wide roaming access service developed for the international research and education community."*[19] This free reciprocal arrangement is possible because NRENs always work in collaboration rather than in competition.

Table 5 summarises the traditional network-related or connectivity services provided by NRENs to HEIs. It should be noted that the growth in the population of non-resident HEI students in multiple private residential facilities means that such connectivity must extend off-campus. Indeed, as evidenced by the COVID-19 closures, the connectivity

15 https://sustainabledevelopment.un.org/content/documents/2106Feasibility-Study-for-a-United-Nations-Technology-Bank-for-the-Least-Developed-Countries.pdf
16 https://www.inthefieldstories.net/why-re-networks/
17 https://sustainabledevelopment.un.org/content/documents/2106Feasibility-Study-for-a-United-Nations-Technology-Bank-for-the-Least-Developed-Countries.pdf
18 https://connect.geant.org/2017/05/15/taking-it-to-the-limit-testing-the-performance-of-re-networking
19 https://www.eduroam.org/what-is-eduroam/

coverage of any NREN (working with the private sector) must be national so that all institutions can use the common opportunity for continuity of teaching, learning, and research regardless of the location of students or faculty.

iv. **Identity and Trust:** developing and implementing systems that ensure that any person who is part of any institution that is a member of any NREN can have their identity verified online, regardless of where they are, and therefore be granted access to the resources of the global research and education community, wherever they exist. Such access is often governed by additional two-party or multi-party agreements.

Table 5: Traditional NREN Services

Main NREN services	Examples
Network services	Connectivity (ALL), eduroam, IPV6, Network Monitoring, troubleshooting, disaster recovery, QoS, managed router services
Security services	CERT/CSIRT, vulnerability scanning, Anti-spam solution, intrusion detection services
Identity services	Identity federation, eduroam, eduGAIN
Collaboration services	Journal access, eduMEET[20], mailing list, email hosting, content management services
Multimedia services	Web conferences, events recording
Storage services	DNS hosting, cloud storage, file sender, virtual machine, web hosting
Professional services	Training and capacity building services

Source: KCL

As the need for collaboration extends beyond national borders, NRENs, typically within the same geopolitical spheres, create regional overlays, the Regional Research and Education Networks (RRENs), which enable collaboration across national borders. Some examples are UbuntuNet Alliance[21], which interconnects NRENs in the countries of Eastern and Southern Africa; WACREN[22], which interconnects NRENs in the countries of Western and Central Africa; ASREN[23], which interconnects countries within North Africa as well as Arab states outside Africa (where it is centred); GÉANT Association[24], which interconnects NRENs in Europe; and RedCLARA[25], which interconnects NRENS in Latin America. The regional networks, connected together, form the global research and education network fabric, serving the global research and education community. It should be noted that within the global context, Africa is the latecomer to research and education networking: Figure 1[26] shows the pervasive presence of RRENs around the world. The specific links shown are to and from GÉANT, and other links (not shown) interconnect other RRENs. It is the unique positioning of GÉANT within this global

20 https://edumeet.org
21 www.ubuntunet.net
22 www.wacren.net
23 https://asrenorg.net
24 www.geant.org
25 www.redclara.net
26 https://www.geant.org/Resources/Documents/GEANT_at_the_Heart_of_Global_Research_and_Education_Networking_Oct_2019.jpg

fabric, combined with the EU's willingness to provide support, that made this pan-European network the logical and easiest route for the new RRENs in Africa to connect to Europe and through that to the rest of the world.

Table 6 gives the NREN membership in each of the African Regional RRENs and shows countries in each region that do not have any NREN. The maturity level of each NREN (0, 1, 2, 3) is derived from a combination of Duncan Greaves' NREN Capability Maturity Model[27] and Mike Foley's levels of NREN development[28] translated:

i. Level 0: No NREN, but varying levels of awareness about the need and ongoing conversations about starting one;

ii. Level 1: Emerging NREN—legal entity established, but with no (or limited) physical network;

iii. Level 2: Connected NREN—physical network with regional/global connectivity to other NRENs and offering basic and some middle-ware services;

iv. Level 3: Mature NREN—physical network with high-speed regional/global connectivity to other NRENs and offering advanced services.

ASREN, WACREN and UA aggregate traffic from over 20 countries across Africa, as shown in Figure 2, and interconnect with the GEÁNT Association to reach Europe as well as RRENs in other parts of the world.

Significant connectivity gaps in Africa are associated with the maturity and effectiveness of the RRENs. UbuntuNet Alliance is the most advanced RREN in Africa. It is not surprising that universities in this region (even with the exclusion of South Africa) generally have much higher bandwidth at much lower prices. RRENs must be recognised as a success factor for the availability of sufficient connectivity, especially in the early stages of NREN development.

Experience has shown that the maturity and sustainability of an NREN depend very much on the ownership and governance models used, the most effective to date being a hybrid model that brings together the strengths of government support and funding on the one hand, and HEI controlled management and operations. Appendix 1 highlights the NREN governance models that are found around Africa.

27 *Greaves, D. (2009). An NREN Capability Maturity Model. https://www.casefornrens.org/Resources_and_Tools/Document_Library/Documents/NREN%20Capability%20Maturity%20Model%20(CMM).pdf*

28 *Foley, M. (2016). The Role and Status of National Research and Education Networks in Africa. World Bank*

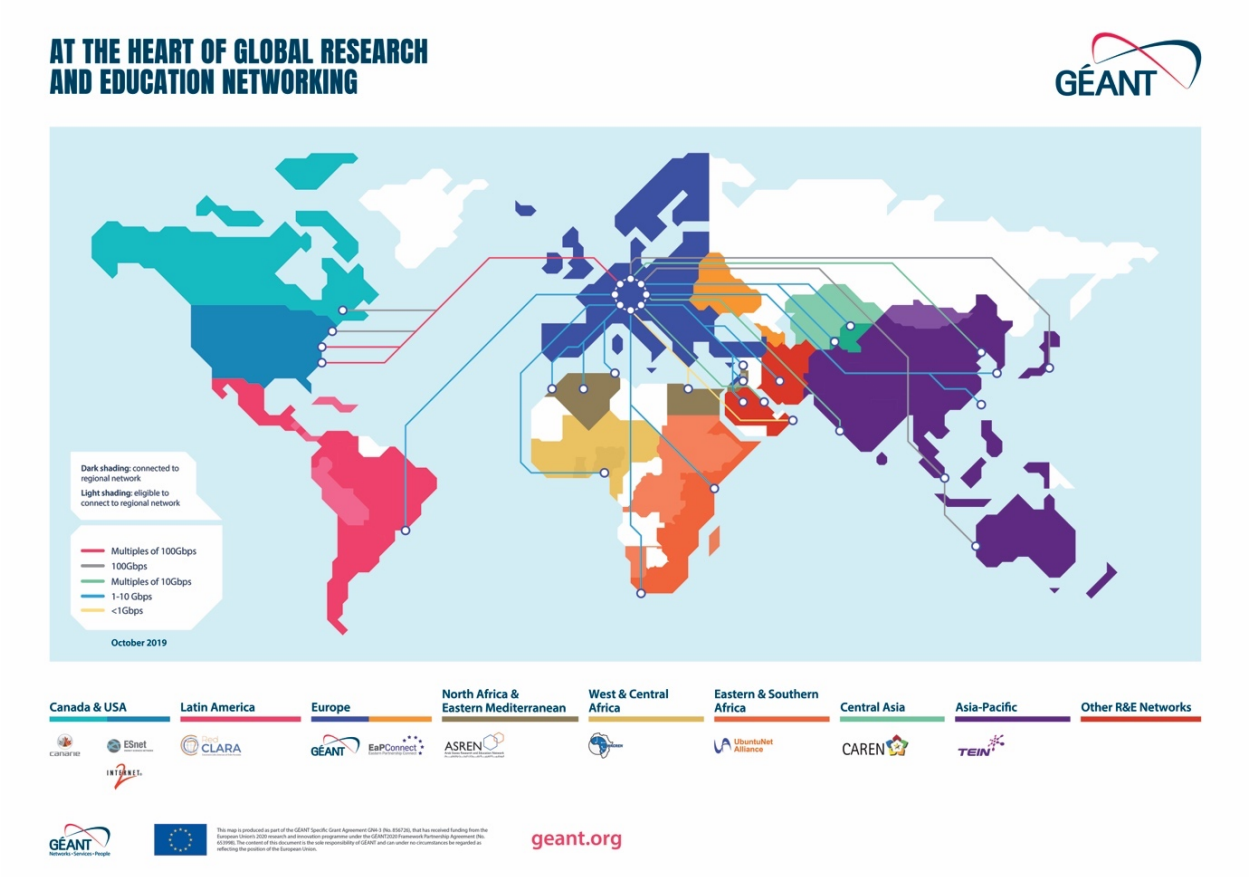


Figure 1: Global coverage of RRENs with interconnections to and from GÉANT

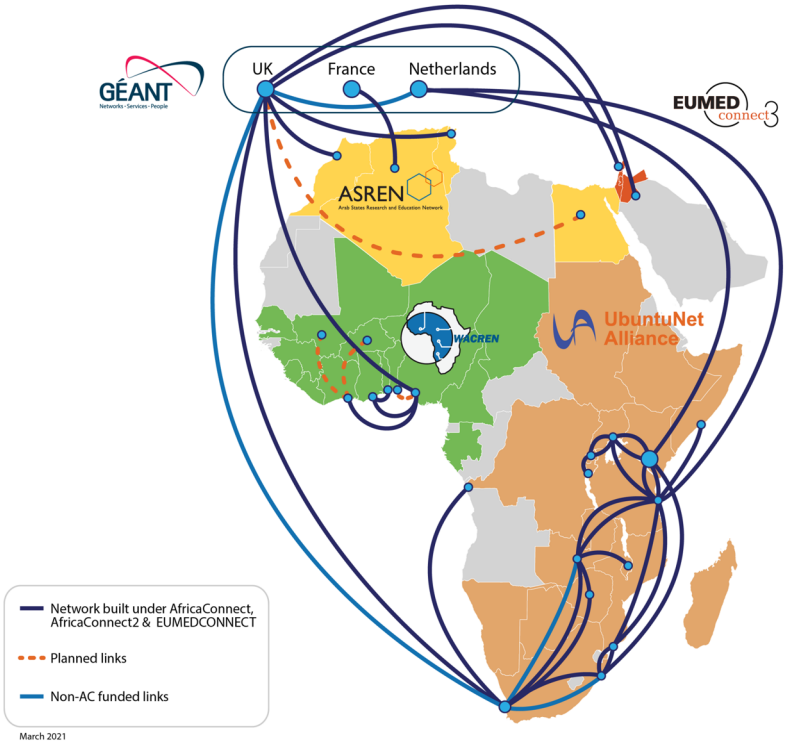


Figure 2: Regional RENs in Africa and connected countries

Table 6: National and Regional Research and Education Networks in Africa

ASREN Region	Maturity Level	UbuntuNet Alliance Region	Maturity Level	WACREN Region	Maturity Level
Algeria: ARN	2	Botswana: BotsREN	1	Benin: RerBenin & RBER	2
Djibouti:		Burundi: BERNET	1	Burkina Faso: FasoREN	1
Egypt: EUN & ENSTINET	2	Dem. Rep. of the Congo: Eb@le	1	Cameroun: RIC	1
Libya: LibREN	1	Ethiopia: EthERNet	2	Chad: TchadREN	1
Mauritania:	1	Kenya: KENET	3	Côte d'Ivoire: RITER	2
Morocco: MARWAN	2	Madagascar: iRENALA	2	Gabon: GabonREN	2
Somalia: SomaliREN	2	Malawi: MAREN	2	Ghana: GARNET	1
Sudan: SudREN	1	Mozambique: MoRENet	2	Guinea: Gn-REN	1
Tunisia: RNU & RNRT	2	Namibia: Xnet	1	Liberia: LRREN	1
		Rwanda: RwEdNet	2	Mali: MaliREN	1
		Somalia: SomaliREN	2	Niger: NigerREN	1
		South Africa: TENET	3	Nigeria: NgREN	2
		Sudan: SudREN	1	Senegal: SenRER	2
		Tanzania: TERNET	2	Sierra Leone: SLREN	1
		Uganda: RENU	3	Togo: TogoRER	2
		Zambia: ZAMREN	2		
		Zimbabwe: ZARNet	1		
Countries without an NREN (Maturity Level: 0)					
Comoros		Angola		Comoros	
		Eswatini		Cape Verde	
		Eritrea		Central African Republic	
		Lesotho		Republic of Congo	
		Mauritius		Equatorial Guinea	
		South Sudan		The Gambia	
		Seychelles		Guinea-Bissau	
				São Tomé and Príncipe	

Source: KCL using data from ASREN, UbuntuNet and WACREN[29]

29 *Other Arab countries that are members of ASREN but not part of Africa have been omitted from this list.*

Appendix 2 provides brief synopses of the UbuntuNet Alliance and a selection of NRENs in Eastern and Southern Africa that demonstrate what is achievable. While the EUMEDCONNECT projects have achieved a lot in connecting countries along the Mediterranean to the GÉANT network in Europe, the examples are not drawn from this region because there was no major emphasis at the time on intra-regional connectivity. Similarly, the WACREN region, while having the same aspirations, embarked more recently on a coordinated approach to regional and global connectivity under AfricaConnect2 and AfricaConnect3.

3.2 NRENs and National Development

While research and education networks were initially conceived and optimised to address the needs of universities and research institutions, they enable and support multiple development fronts, many of them responding specifically to the Sustainable Development Goals[30] including SDGs 4 (Quality Education), 8 (Decent Work and Economic Growth), and 9 (Industry, Innovation, and Infrastructure). Developing countries are fund-constrained and must prioritise those areas of activity that combine specific focus with cross-cutting benefit to large swathes of the population. How do NRENs fit the bill in this respect? Some examples are highlighted below.

i. NRENs as Trusted Stakeholders in the Digital Africa Agenda

Countries in Africa have embarked on the development and implementation of national digital agendas. Expert guidance and support for these are available mainly in commercial and academic circles. However, the commercial sector is not a neutral party because the agendas necessarily come with a lot of commercial opportunities. NRENs are, however, non-profit, making them a trusted party working in the best interests of their users. Mature NRENs are also a source of free expert advice to governments on digital agendas.

ii. NRENs Support School Connectivity

The transformation of developing countries to knowledge societies cannot happen when most students start using computers and online applications only at the upper secondary or higher education levels. Changing the situation calls for investment in teacher competencies (for transition to ICT-supported online learning), computer resources, and connectivity – starting at the earliest levels of education.

Schoolnets were started in various African countries to address the connectivity needs of schools. Unfortunately, such attempts failed in most cases, especially due to the challenges in sustainably operating large national-level data transport and distribution networks to serve large numbers of widely dispersed schools. Such networks demand the kind of advanced engineering, technology, and organisational skills that are at the core of NRENs. NRENs can, therefore, at marginal cost, extend these to the management of a larger network that also connects schools. The collaboration of state RENs with Kindergarten to Grade 12 (K-12) in the USA is a very good example, as are many examples from Europe. An example from Africa is

30 https://www.un.org/sustainabledevelopment/

the Research and Education Network of Uganda, RENU, which now extends connectivity to senior secondary schools. There is, however, a lot more that goes into a Schoolnet than connectivity, and responsibilities beyond this are best left outside the ambit of the NREN, which could otherwise be over-extended.

iii. NRENs support Telecom sector growth

NRENs high-speed backbones are realised by largely utilising the services of licensed commercial service provider networks and/or national fibre networks. In addition to this direct benefit for commercial operators, NRENs drive the growth of bandwidth demand: The percentage of the population that possesses the requisite levels of computer, Internet, and information literacy in most African countries remains too low to have any major impact on national development. To achieve growth in demand, the habit of usage (along with associated benefits) must penetrate the educational sector. The graduates of tertiary institutions are the future employees, employers, heavy users, decision-makers, and revenue generators. For the telecommunication service providers, ensuring that schools and NRENs can access high-quality bandwidth at very low costs is an investment into their future markets, guaranteeing growth and sustainability.

iv. NRENs Expand Government' Income from the Telecommunications Sector

In most developing countries, especially those that have opened up the sector to full competition, the telecommunications sector is one of the biggest contributors to government revenue. For the government, funding access to connectivity for the education sector and supporting research and education networking has a dual benefit: first, it ensures that usage will rise to a level that will start having a positive impact on economic growth, which only occurs beyond a certain threshold; and second, it assures growth in future government revenue. It should be noted that there are several countries in Africa, including Zambia, Uganda, and Rwanda, where the telecommunication regulators have supported or continue to support the NRENs of their countries.

v. NRENs Drive Universal Access/ Service – Change from a Supply-Side to a Demand Side approach

Universal Access and Service have traditionally been looked at as supply-side challenges, which has defined the policies and sector regulation in most countries. However, the dynamic that justified a supply-side approach is changing in many developing countries. Those people who experience the benefits of access to telecommunication services demand that such services are ubiquitously available. They are willing to pay reasonable prices for the convenience and benefits they get. It is time for governments to change from pushing penetration to pushing demand so that penetration becomes a response to pull factors (from the users) rather than push factors (from governments and regulators). This will happen if investments are made at all levels of education to develop in children and young people the habit of usage, and appreciation of the benefits of online applications and services, creating the sustainable demand that will pull the growth of coverage and services.

vi. NRENs provide Research Test Beds and Capacity Building Environments

In any country, NRENs will have the most extensive integrated network with research and education support at the core of its mandate. NRENs, while addressing their core mandates, therefore offer multiple opportunities to developing countries, including:

- Research testbeds for frontline technology and development topics like big data, Internet of things, cybersecurity, and advanced data networking techniques;
- Capacity building opportunity for network engineers (of whom there is an acute shortage in Africa), including practical training for those who are still students.

All this can be done because NRENs, not being commercial operators, have greater liberty in what they can do on or with their data networks.

vii. NRENs Enable National Science and Technology Agendas

Most countries in Africa are placing increasing emphasis on science and technology and have indeed set up ministries specifically responsible for the penetration, localisation, and development of science and technology. The space provided by NRENs is a unique enabler for this, especially if it includes schools: it brings together all players in this interconnected and collaborative environment. Science and technology in developing countries will only take root if students, even at the lowest levels of education, are not strangers to trends, opportunities, and challenges in these areas; and have also got access to the best science educators.

viii. NRENs Drive Growth of Gross Domestic Product (GDP)

The research conducted on CANARIE[31], the Canadian Research and Education Network gives some very good insights into this. The research showed that the CANARIE environment led to:

- Increase in demand for telecommunications equipment and services;
- Creation of jobs;
- Reduction in direct expenditure on bandwidth by universities;
- Increase in big science and data-intensive research that attracted and retained highly skilled human resources, driving up productive capacity and therefore GDP; and
- The attraction of major Research and Development funding leads to the creation of new knowledge and development and commercialisation of innovative products and services, all having a major positive impact on GDP.

The headline finding from the study was that ***"the economic benefits' analysis indicates that every dollar of investment in the Canadian R&E sector through CANARIE generated $2.85 in economic benefits in the form of GDP for the Canadian economy"***.

31 https://www.canarie.ca/wpdm-package/canarie-economic-benefits-analysis-2014/

Some effects from the CANARIE research might not apply directly to developing economies in Africa that, for example, still import all their networking equipment, but this in itself becomes an opportunity for such countries to rethink their strategies for sustaining ICT services and systems in a knowledge economy.

4. REN Influence on the Connectivity Landscape over the Last Fifteen Years

The collective action of REN pioneers, advocates, and funding partners, both within and outside the continent, has led to major changes in the connectivity environment in Africa, not just for the HEIs, but for the countries themselves:

i. Influencing service providers to move towards true cost-based pricing: The combined capacity of HEIs connected to an NREN often makes it one of the largest single consumers in the country. This brings pressure to bear on general market pricing, and this benefits all users, contributing to national universal access and service agendas.

ii. For HEIs, the increasing maturity of NRENs and RRENs has led to continuing drops in pricing. Data from institutions indicates that current bandwidth per university ranges between 10 Mbps to 10 Gbps. An exception is South Africa, where few large universities are moving to 50 and 100 Gbps connections. Bandwidth prices range from US$2 to US$900 per Mbps/month depending on the volume of bandwidth consumed, the market structure and the regulatory environment.[32]

   The Uganda NREN, RENU, is an illustrative example to show how prices paid by HEIs for bandwidth have changed over the last ten years (see Figure 3). RENU and connected institutions currently use more international capacity than the current use by all government ministries and agencies.

iii. While it is still limited, there is increased awareness among governments and their agencies about the role and importance of NRENs, leading to increasing support through enabling licencing and in-kind support or funding. The Eastern and Southern countries that have achieved major progress—South Africa, Mozambique, Zambia, Kenya, and Uganda—have received combinations of major support in kind, as financing, enabling policy and regulation, from governments and their agencies.

32 *WBG Feasibility Study for connecting all African universities and TVETs to broadband.*

Source: Research and Education Network of Uganda, RENU

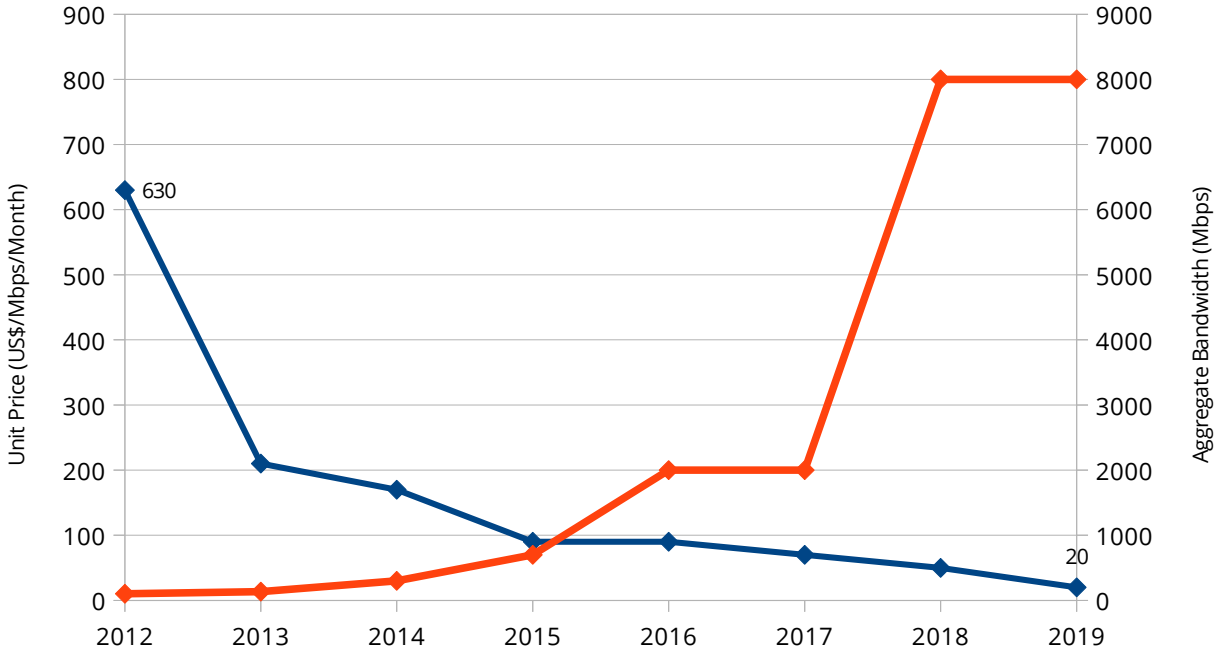


Figure 3: Bandwidth supplied to HEIs in Uganda by RENU and price trends

iv. There is increased awareness among development partners, to the extent that connectivity for HEIs in Africa through support to RRENs and NRENs is now on the development support agendas of major funders like the European Union (EU) and the World Bank. More importantly, these two have co-funded (through different channels but to the same end) connectivity to, e.g., SomaliREN, MoRENet, and MAREN. It should be noted that the recognition of Indefeasible Rights of Use (IRU) purchases as a cost-effective way of supporting connectivity in developing regions was passed on to the EU in the early days of AfricaConnect by African pioneers and informed current procurement approaches used by GÉANT.

In addition to the major changes above, there are very many specific examples[33,34] of how NRENs have enabled the achievement of specific research projects and collaborations, or supported HEIs in ensuring learning continuity during the lockdowns triggered by COVID-19. While these are primarily anecdotal, they underscore the outcomes of the growth of REN activity in Africa and provide a forward view of the potential impact when broadband connectivity becomes ubiquitous throughout the education sector. GÉANT, with their much higher capability, was able to develop specific interventions to ensure continuity of education and research right from the early stages of the pandemic: *"In addition to the fundamental connectivity and key services, the greatest demand has been for tools and services enabling real-time communications and remote learning. GÉANT and the NRENs have been able to meet this demand both through their offerings, accelerating and customising these where possible (e.g., eduMEET and openUp2U), and through facilitating commercial offerings."*[35]

33 https://www.inthefieldstories.net/network/africa/
34 https://ubuntunet.net/2021/02/renu-powers-surgical-operations-in-uganda/
35 https://www.geant.org/Projects/GEANT_Project_GN4-3/GN43_deliverables/D3-9_GEANT-Support-for-RandE-during-the-Early-Stages-of-the-COVID-19-Pandemic.pdf

5. Roles Played by Development Partners[36]

Development partners have been and must remain key players in the African connectivity agenda if sustainable change, which calls for a massive upfront injection of resources (funding, knowledge support, capacity building, and implementation support), is achieved. The historical and ongoing roles of development partners are recognised in this section.

Foundational support came from various sources, examples of which include the following:

i. The Partnership for Higher Education in Africa supported the African Bandwidth Consortium, a pioneering model in the regional aggregation of bandwidth.

ii. The Leland Initiative, funded through USAID, provided wireless backbones to campuses in selected countries.

iii. Fostering Research and Education Networking in Africa (FRENIA), funded by the Andrew W. Mellon Foundation and managed by TENET, provided funding for the start-up of NRENs.

iv. The International Development Research Centre of Canada, through its ACACIA programme, especially fostered and supported the Research and Education Networking Unit of the Association of African Universities (AAU) and Regional Research and Education Networks, including the UbuntuNet Alliance and the West and Central African Research and Education Network.

v. AAU was a key continental level policy advocate in securing licences for the pioneer NRENs, getting special rates for ASN and IP address space for African NRENs and RRENs, and in negotiations with development partners[37].

vi. The Open Society Foundation, and Open Society Initiative of South Africa, provided support to the UbuntuNet Alliance in the start-up stages.

vii. Foundations such as the Bill & Melinda Gates Foundation, Carnegie Corporation, Rockefeller Foundation, Ford Foundation, John D. and Catherine T. MacArthur Foundation, William and Flora Hewlett Foundation and Andrew W. Mellon Foundation have been playing roles in the development of the capacity of higher education institutions in Africa. These foundations did not only provide funding but also carried out a considerable analysis into the problems of connectivity, content and knowledge sharing among academic and research institutions and libraries in Africa.

36 *See Report 1 of the WBG Feasibility Study "A Connectivity Gap Analysis and review of Existing Programmes".*

37 *The 11th General Conference of the Association of African Universities, held in Cape Town in February 2005, mandated the Secretariat of the Association to assume a focal point role in initiatives aimed at enhancing access to and effective utilisation of ICT and the Internet by its members, starting with access to higher bandwidth at a lower cost.*

viii. Continuing support has come from the European Union Commission, through the AfricaConnect and EUMEDCONNECT projects.[38] To date, the two projects have deployed the highest level of resources to support and grow both connectivity and other aspects of NRENs and RRENs in Africa. The AfricaConnect projects were preceded by EUMEDCONNECT, EUMEDCONNECT2, and EUMEDCONNECT3[39] that was primarily focused on connecting the Mediterranean countries to Europe. The much greater impetus to REN growth has come from the AfricaConnect projects that emphasised supporting the growth of regional networks, which, in turn, positioned African NRENs to achieve their missions faster. Alongside these were the EUC Horizon 2020 (H2020)[40] projects including TANDEM[41], Sci-GaIA[42], and MAGIC[43] that ended during 2017. TANDEM especially positioned WACREN, where progress during AfricaConnect was limited, to be prepared for the successful implementation of AfricaConnect2.

ix. The World Bank has provided direct funding: Burundi, Mozambique, Tanzania, Somalia, Malawi, and Nigerian NRENs[44] are among the beneficiaries. While not planned directly for university connectivity, the World Bank Regional Communications Infrastructure Project[45] (RCIP) has benefited universities in Rwanda, and much earlier on, Kenya.

Other partners of higher education connectivity include:

i. Multinational companies including CISCO, Google, Intel, Juniper Networks and Microsoft that provide tools and equipment at concessionary prices along with training opportunities.

ii. Research networks (and through them, their member NRENs) that provide technical assistance and experiential support – GÉANT Association, RedCLARA and Internet2.

iii. NSRC and the Internet Society (ISOC)[46], both of which have played and continue to play a major role in training NREN engineers on network operations and management; and

iv. The African Internet Registry (AfriNIC) in delivering IP numbers and other resources at concessionary rates.

A review of the different initiatives brings out the following key lessons:

i. The need for cohesion: all the efforts around access, capacity, and content focus on the same end beneficiaries. There has been some increase in collaboration among development partners over the years, multiplying the benefits of independent initiatives. The next step should be cohesion so that, to the extent possible, an

38 *https://africaconnect3.net*
39 *https://www.eumedconnect3.net/Pages/Home.aspx*
40 *https://ec.europa.eu/programmes/horizon2020/*
41 *https://cordis.europa.eu/project/id/654206*
42 *http://www.sci-gaia.eu/osp/*
43 *https://www.h2020.md/en/magic-h2020*
44 *The support to Tanzanian universities was directed through a government Ministry. It subsequently ran into challenges of sustainability.*
45 *https://www.worldbank.org/en/search?q=Regional+Communications+Infrastructure+Program*
46 *https://www.internetsociety.org*

integrated programme approach can be used to create even greater synergy.

ii. The need for beneficiary contribution and driving direction: The AfricaConnect initiatives have demonstrated beneficiary contribution as a key aspect of sustainability. They have also been responsive to beneficiary needs and direction, with outside expertise bringing on board, especially procurement and communication skills. Networks in the Alliance region have been implemented and are operated by the owners.

iii. Government support: Many of the NRENs are challenged by the need to contribute to any initiative, and the smaller ones much more so. This does not reduce the necessity of such contribution but instead points to the need to get government commitment to counterpart contribution before any intervention. African governments need to take ownership of the national and regional RENs as critical development necessities. Where governments are not committed, investments will not be sustainable.

6. Addressing the Remaining Barriers

It is very evident that despite the progress made, and outside a few exceptions (mainly in Egypt and South Africa), the gap in connectivity between African countries and the rest of the world remains enormous—but it is not insurmountable.

It was established during the early 2000s that universities within Eastern and Southern Africa were spending about $800,000 per month on satellite connectivity. The UbuntuNet Alliance argued that if connectivity via fibre was available, with prices at par with the rest of the world, this money would have provided a sufficiency of bandwidth for the HEIs in the region. As an illustration, Makerere University, the largest in Uganda, has spent about $40,000 per month on connectivity for the last 20 years. This provided 10Mbps in the early 2000s, which increased to about 30 Mbps during the life of the African Bandwidth Consortium a few years later. It is now at 2Gbps through the Research and Education Network of Uganda, RENU, and the UbuntuNet Alliance. Were the price to go down to the $0.1 per Mbps/month – and that is still higher than within many developed countries – Makerere University would afford 400Gbps: the real challenges are cost, not inability to pay. However, the cost is just a symptom of the many underlying and well-known barriers. Interventions should focus on these remaining barriers to maximise the value and benefit of any funding support.

Figure 4 shows the key areas where divides in access occur, addressing the global, regional, national, campus, and individual levels. Regional, national, and higher education connectivity environments are diverse, and the challenges are therefore contextual: best practice can be followed, but solutions have to be tailored to each country. Action is particularly needed in addressing the following major areas where large gaps exist over most of the African continent:

i. Creating policy and regulatory environments (or eliminating barriers therein) to enable growth in competitive national and regional connectivity environments. Competitive development is required in coastal and inland marine fibre landing points, national and transnational terrestrial fibre, and carrier-neutral data centres. The development of internet exchange points is a key requirement in keeping local traffic local in any country and its sub-divisions.

Source: KCL

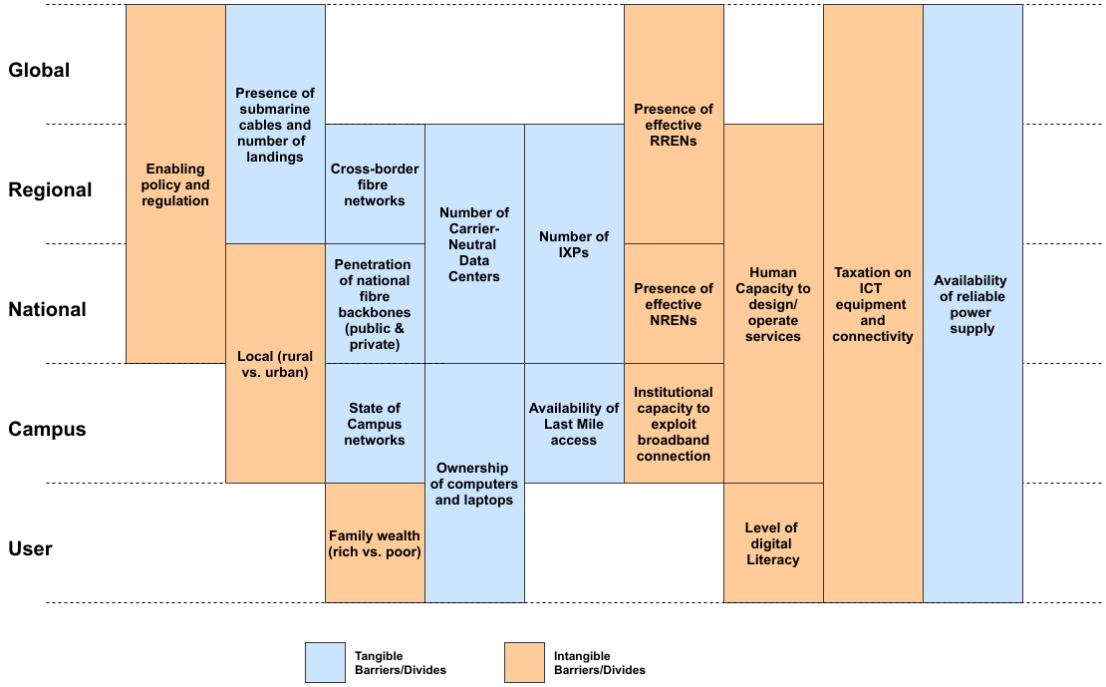


Figure 4: Causes of Divides in Access

ii. Addressing *"last mile"* and *"last inch"* access through the development of sufficient, resilient, and scalable campus networks as well as their connection to high-capacity backbones that have national penetration; and ensuring, through different schemes, individual ownership of laptops by all students and staff in HEIs.

iii. Addressing awareness and knowledge gaps concerning the major positive impact of high-quality broadband on the many ways in which HEIs contribute to national development; the major differences between REN and commercial data connectivity; and the need for governments to support the growth of NRENs as one of the key national development strategies.

iv. Engaging development partners to implement massive coordinated interventions that will ensure accelerated and sustainable change.

These are broken down further in terms of supply-side and demand-side gaps and barriers in Table 7, which provides a summary of the key barriers, what needs to be done to address them and by who.

Table 7: Key Barriers to HEI Access to Broadband, Key Stakeholders responsible, and Required Actions

	Causes of Divides	Key stakeholders and actions to address barriers
A	**SUPPLY SIDE**	
1	Lack of enabling policy and regulation that would stimulate competitive broadband ecosystems along with the growth of RENs. The major underlying causes are a combination of limited awareness and appreciation of the potential development impact; and how to create the right environment.	This is the responsibility of national governments. Development partners can play a major role in supporting the creation of awareness and appreciation; identification of policy and regulatory gaps; and formulation to address these gaps with respect to the broadband ecosystem.
2	Specific to landlocked countries are the often very high costs of regional transit due to insufficient or deficient regional regulatory approaches.	This is the responsibility of both national governments and regional economic communities. Policy and regulation within a framework of regional collaboration, and seizing the opportunities of the African Continental Free Trade Area (ACFTA)[47] would enable inland landing stations and/or cost-based regional transit.
3	For coastal countries, the number of, and competition among submarine cables landing in the country. It should be noted that even when there is such access, monopolistic approaches to such stations can constrain consumers' choices.	This is entirely under the control of national governments. Good policy and regulation, combined with good investment policies, will create the environments that attract marine cables. This will be enhanced if the environment also provides cost-based transit to the inland countries, expanding the market for cable operators.
4	Number of, and competition among terrestrial transnational fibre networks, particularly for landlocked countries, to access submarine capacity.	This is the responsibility of national governments and regional economic communities, calling for similar approaches to (2) above.
5	Number of, and competition among national backbone fibre networks to distribute capacity across the whole country. It is those countries in Africa with competing providers that have created better broadband ecosystems.	This is the responsibility of national governments, calling for policy and strategies for national fibre coverage within competitive infrastructure arrangements—pervasive national coverage through monopolies, whether private or government, is counter-productive. A balance is required among three aspects: benefits of infrastructure sharing, ensuring national penetration, and creating a competitive environment.
6	Presence and maturity of NRENs and RRENs.	HEIs have a responsibility to lead collaboration and establish NRENs to ensure responsiveness to user needs. National governments are responsible for providing ongoing support while leaving management and operations to HEIs. Experience has shown that championing by HEIs that also secure

47 *https://au.int/en/cfta*

	Causes of Divides	Key stakeholders and actions to address barriers
		government support leads to rapid REN growth and faster achievement of national benefits.
7	Presence and number of internet exchange points (IXP) and carrier-neutral data centres and the interaction between these two components[48].	It is in the national interests of any country for the government to catalyse the development of carrier-neutral data centres and IXPs using PPP approaches. Good regulation and a liberalised competitive market, combined with a good investment environment, also drive private sector investment into these key infrastructure elements.
8	Availability of reliable power.	While pervasive availability of power is a recognised challenge that will take decades to address in most African countries, renewable sources – and especially solar – are becoming more efficient and cheaper, especially in all sizes. Governments can develop policies and strategies that attract investment in renewable energy sources, leading to market growth and reducing costs.
B.	**CONSUMER SIDE**	
1	Low levels of digital literacy among HEI students and staff. This affects those from the poorer sectors of society most. Low digital literacy is a result of poor integration of ICT into education starting from the foundational levels.	Governments have primary responsibility for this, starting at the policy level and getting into real funding through annual budgets. Development partners can act as a knowledge resource for awareness and appreciation and policy formulation and implementation so that digital literacy is a priority, especially at the lower levels of education.
2	Lack of interest and commitment from the governance and managerial levels of HEIs. Similar to the government level, the major underlying cause is limited awareness and appreciation of the role of ICTs in achieving the institutional mission and strategic priorities. This is compounded by the perception of ICT and its use as the responsibility of the ICT experts – a challenge that cuts across the business owners and most ICT professionals.	Governing councils and top executive of HEIs need to take ownership for broadband connectivity down to the user level, moving away from the currently common practice of leaving it to ICT Directors. ICT directors can drive this if they appreciate that their role is to enable and support the organisational business processes, leaving leadership to business experts (academic, learning, library, research, finance, human resource, administration, and records management).
3	Limited investment in campus ICT infrastructure coupled with poor remuneration for, and shortage of competent ICT professionals, leading to poorly designed networks that are not fit for purpose.	This is primarily an HEI strategic prioritisation challenge: Limited investment in creating an ICT-enabled environment and lack of competitive salaries for competent ICT personnel may be constrained by funding but is primarily caused by low prioritisation in HEIs. This is also linked to a lack of awareness,

48 *World Bank Group, 2020. National Data Infrastructure The Role of Internet Exchange Points, Content Delivery Networks, and Data Centres (still in draft form)*

	Causes of Divides	Key stakeholders and actions to address barriers
		interest and commitment at governance and managerial levels.
4	Limited access to laptops and other computing devices by students and staff of higher education institutions.	This gap needs to be addressed at the national level and enforced through the educational regulatory agencies. It needs to be a requirement starting at national policy for across the board individual ownership of laptops in HEIs, and an HEI requirement for each student and staff member to have a laptop. This drives the next level: schemes for ensuring such ownership. Laptop ownership schemes must be required to ensure that those constrained by poverty can also acquire laptops.

Source: KCL

In addition to taking action as summarised in Table 7, the following actions are recommended for national governments:

i. Understand NRENs, and define how they fit into the overall national development strategy

The allocation of limited resources to different strategic priorities must be founded on a clear understanding of the expected roles and national benefits. How does the NREN fit into this strategy? What else needs to be addressed to enable the NREN to play its expected role? If the NREN is expected to provide connectivity to schools, the institutional arrangements through which this will be done must be addressed as a co-requisite.

ii. Engage the NREN (or where it does not exist, the Research and Education Sector to establish such NREN) in order to agree on roles and expectations

While NRENs are a growing feature in the sub-continent, there are countries where they do not exist. Governments will need to play the initial champion role of convening the heads of research and education institutions to establish the NREN. Regardless of the starting point (existing or new NREN), there needs to be an understanding of the roles and expectations of government and the NREN. Roles and expectations should be spelt out, documented, and formalised through agreements. The agreements should spell out:

- The governance relationships and objectives;
- The role of the NREN and expected deliverables;
- The role of government and its agencies, and how they will jointly support the NREN to achieve the objectives. Government and its agencies can contribute to NREN costs, either directly, or indirectly through free access to infrastructure like the national fibre backbones.

iii. Establish an enabling environment for the NREN to operate as a not-for-profit closed user-group that also has linkages beyond national borders

It needs to be appreciated that NRENs, not being commercial, should not be subject to taxation. This is regardless of the governance model. Secondly, while NRENs will normally rely on commercial providers for connectivity, there will be instances where they (the NRENs) need to roll out segments of their networks. NRENs should therefore be licensed in a way that enables them to do this for their closed user group. Finally, NRENs are part of a global network and need authorisation to transit traffic for other NRENs and communicate across borders.

7. Conclusion

For African countries, the key takeaway from this paper is that NRENs are not just the business of universities but the business of government. They are a strategic tool for developing countries in which governments need to take an active interest in promoting the growth of NRENs, supporting them, assigning them development responsibilities, and making them accountable to the government while leaving management and control to the member institutions. NRENs are a strategic opportunity for national development.

For HEIs, the key takeaway is that acceptance by governments to support and fund NRENs must be founded on active interest and prioritisation by the HEIs themselves. The mature NRENs in Africa have been driven by the commitment of HEIs not just in intent but in prioritising and allocating resources for improved campus networks and increased bandwidth. The growth of NRENs and their benefits will depend on the interest and support of the Rectors, Vice-Chancellors, and Presidents, not ICT Directors.

For development partners, the key takeaway is that while they have done a lot in supporting the development of African NRENs, much more needs to be done on a massive and coordinated scale, to overcome the gravity of the multiple challenges and get to a sustainable trajectory. The entire world will reap the benefits.

Appendix A: NREN—What Governance Model is Appropriate?[49]

A common challenge in African countries has been deciding who owns the NREN and how it should be governed – and this has indeed caused many incipient NRENs to freeze in their early stages of development. Ownership is not the problem: the problem usually is the absence of a shared vision that enables a positive collaborative relationship. There is no "single model fits all" solution, but experience in Africa over the last ten years has given a clear indication of what works best. Each country has its distinctive political dispensation, and how NRENs develop or are supported by governments will vary from country to country. The three common approaches are briefly described below. As will be noted, the models are not mutually exclusive.

i. Bottom-Up (or Grassroots) NRENs

These are NRENs that are initiated, owned, and funded by universities and research institutions. Successful and mature examples in Africa include TENET in South Africa; KENET in Kenya; RENU in Uganda; and ZAMREN in Zambia. Grass-roots NRENs benefit from organisational structures that permit rapid decision-making and organisational agility essential for survival in the dynamic ICT sector. They are also very responsive to member needs because the members are the top policy body that sets up the Board and executive arms of the NREN. They will, however, find it harder, especially in the initial stages, to gain recognition and acceptance by governments, and they will always have to lobby hard where public sector funding is needed.

Except in situations where many the member institutions are well funded, full inclusion of potential members requires government and governmental agencies to provide support for grass-roots NRENs, either directly or through the member institutions: the four examples cited above are grass-roots NRENs that have also benefited from the support of governments and government agencies.

ii. Top-down

These are NRENs initiated and owned by the government, for example, EthERNet in Ethiopia; RwEdNet in Rwanda; and MoRENet in Mozambique. Top-down NRENs are subject to the typical environment of any government-managed institution. These include prolonged and procedure bound processes that disable tactical decision-making and lead to poor responsiveness to the needs of the institutions they serve.

49 *See also the author's contribution on NRENs under eTransform Africa, the Education Sector (See Summary at http://siteresources.worldbank.org/EXTINFORMATIONANDCOMMUNICATIONANDTECHNOLOGIES/Resources/282822-1346223280837/Education.pdf, and full report at http://siteresources.worldbank.org/EXTINFORMATIONANDCOMMUNICATIONANDTECHNOLOGIES/Resources/282822-1346223280837/Education_Fullreport.pdf*

The development and progress of the Top-down NREN examples above have been prolonged. They, however, have an advantage of support by their governments, making them more easily financially sustainable, provided government recognises them as a priority. The difference in the levels of maturity of the EthERNet, RwEdNet, and MoRENet is a good demonstrator of how awareness of benefit and priority attached by the government makes a big difference:

- EtheRNet has access to high capacity over the national backbone and a well-equipped network operations centre. They are, however, not allowed to have external connectivity, a monopoly of the incumbent operator, which also connects to all universities.

- RwEdNet has for more than ten years been trying to set up governance and operational structure, until recently when the University of Rwanda was asked to take the lead. Rwanda has one of Africa's most extensive national fibre networks, a monopoly whose operations are outsourced to the private sector. Bandwidth to HEI in Rwanda is still very limited.

- MoRENet has been funded by the World Bank through the government, is operating an extensive fibre network. The start was very slow for the first ten years but has ramped up over the last five years.

iii. Cooperation between government and universities

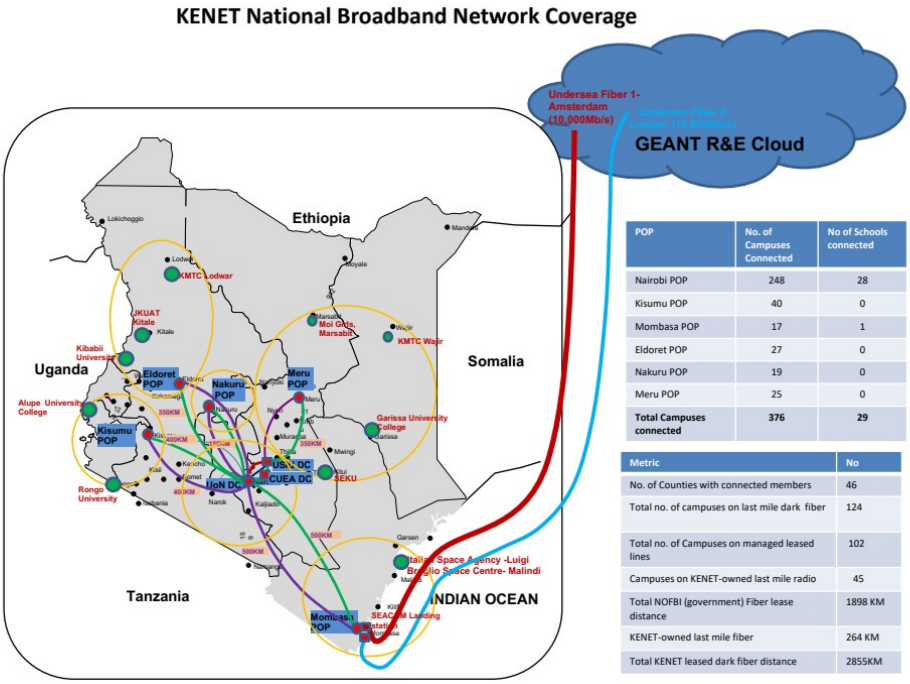
In this model, there is mutual recognition of government roles on the one hand and research and education institutions on the other in creating an effective NREN. The cooperative model, if well handled, produces the best of both worlds: availability of funding from the government; and management and control by the universities through a Board and executive arrangement selected by members (with possible government representation). This model permits the NREN to be managed and operated with the structures and efficiency of a private sector organisation while maintaining accountability to both government and the members. The best example of this cooperative approach on the African continent is South Africa: While TENET started and is operated as a grass-roots NREN, SANReN—owned by the government of South Africa—later brought onboard high capacity national and international connectivity that has been entrusted to TENET to manage and operate. TENET and SANReN operate under a cooperative umbrella called the South Africa NREN: SANREN. It should be noted that this cooperative arrangement can be transitioned to, regardless of whether the NREN was started by HEIs or by the government, though the process can be extended. A key element in achieving this is trust, which enables the strengths of each side to create the synergy required for sustainability.

Appendix B: Illustrative Cases: KENET, TENET, RENU and UbuntuNet Alliance

B.1 Kenya Education Network (KENET)

The Kenya Education Network (KENET)[50] is Kenya's National Research and Education Network (NREN) through which universities access broadband connectivity in the country.

Source: KENET, 2021



POP	No. of Campuses Connected	No of Schools connected
Nairobi POP	248	28
Kisumu POP	40	0
Mombasa POP	17	1
Eldoret POP	27	0
Nakuru POP	19	0
Meru POP	25	0
Total Campuses connected	**376**	**29**

Metric	No
No. of Counties with connected members	46
Total no. of campuses on last mile dark fiber	124
Total no. of Campuses on managed leased lines	102
Campuses on KENET-owned last mile radio	45
Total NOFBI (government) Fiber lease distance	1898 KM
KENET-owned last mile fiber	264 KM
Total KENET leased dark fiber distance	2855KM

Figure 5: Schematic Map of KENET Network

Some key highlights on KENET's operational processes and network infrastructure include:

i. Network connections had grown from 6 campuses across four universities in 2001 to 360 campuses across about 140 Universities and TVETs in 2020.

ii. KENET had connected 135 of 360 campuses using fibre by 2020.

iii. KENET operates close to 3000 Km of fibre to connect universities. It leases about 40 Gb/s of managed fibre from commercial operators like Liquid Telecom for both last mile and backbone links, 2960 Km of dark fibre primarily from government and has built over 264 Km of own last mile fibre to connect universities and research institutions leveraging government financing, donor funding, and contributions from member institutions.

iv. The total amount of bandwidth procured by KENET has grown from 1.2 Gbps in 2013 to

50 *https://www.kenet.or.ke/*

20 Gbps in 2020. This is composed of 2 x 10 Gb/s redundant L2 circuits to Europe on SEACOM and EASSy/WACS cables.

v. The unit price of bandwidth for member institutions has fallen from about USD 1158 (per Mbps/month) in 2010 to about USD 5 (per Mbps/month) in 2020.

vi. KENET employs a tier system for charging members—more consumption of bandwidth results in lower per-unit pricing. Member institutions pay between USD 5 - USD 80 per Mbps/month depending on the volume of bandwidth that they consume (see Table 8).

Table 8: KENET's tier pricing varies based on the amount of bandwidth procured

Capacity (Mbps)	US$/Mbps/month
< 5	80
5 - 9.9	60
10 - 29.9	30
30 - 99.9	25
100 – 399	20
400 – 999	15
1000 - 3999	10
4000 and above	5

Source: KENET, 2020

KENET's biggest consumer at the moment is Nairobi University, which receives 3 Gbps. With an enrolment of 84,000 students, this works out at 35.7 Mbps @ 1,000 students. This is still far below the progressive bandwidth target of 200 Mbps @1,000 students in 2020 or the 2 Gbps @ 1000 students in 2025. KENET generates 91% of its funding from the sale of bandwidth, 6% from external budget support, 2% from cloud services and 1% from membership fees. The ministry of ICT is currently extending a 100 Gb/s fibre link to the KENET data centre from the Mombasa TEAMS cable landing site and the National Konza Technolopolis that will host some national physical science labs and data centres for innovation and research.

B.2 Tertiary Education and Research Network of South Africa (TENET)

The South African Research and Education Network (SANReN)[51] depicted in Figure 6 is managed by the Council for Scientific and Industrial Research (CSIR) and the Tertiary Education and Research Network of South Africa (TENET).[52] The network connects over 500 sites across all nine South African provinces to the network, including universities, science/research councils, national facilities and institutions, academic hospitals, and museums. This also includes high capacity long-haul circuits to the Hartebeesthoek Radio Astronomy Observatory (HartRAO), the South African Astronomical Observatory (SAAO) in Sutherland, the South African National Space Agency (SANSA)'s magnetic in Hermanus, and the developing Square Kilometre Array (SKA) site in Carnarvon.

Source: SANReN

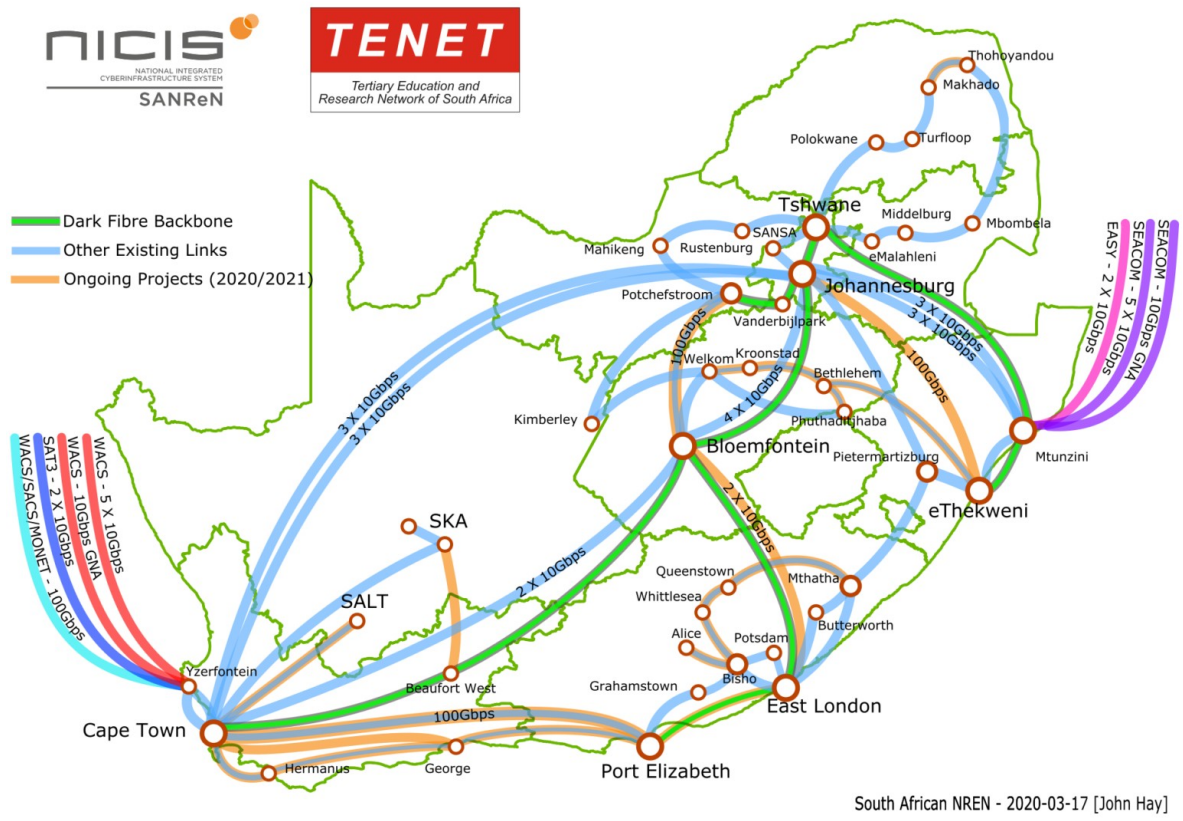


Figure 6: South African NREN backbone map showing the terrestrial and undersea capacity

51 *http://www.sanren.ac.za/*
52 *http://www.tenet.ac.za/*

Some key highlights on TENET's operational processes and network infrastructure include:

i. Network connections have grown to cover over 386 university and research sites and over 90 TVET sites through South African Broadband Education Networks (SABEN) in 2020.

ii. The SANReN backbone includes about 3,000 km of its own dark fibre backbone and about 6,000 km of managed bandwidth links at speeds of up to 100Gbps.

iii. The total amount of bandwidth procured by TENET has grown from XX Gbps in 2010 to 260 Gbps in 2020. This consists of capacity on five undersea cables (SEACOM, EASSy, WACS, SAT-3 and WACS/SACS/MONET) summarised in Figure 6.

iv. The unit price of bandwidth for member institutions has fallen from about USD 1,910 (per Mbps/month) in 2009 to about USD 2 (per Mbps/month) in 2020.

B.3 Research and Education Network of Uganda (RENU)

The Research and Education Network for Uganda (RENU)[53] is a not-for-profit organisation that manages the National Research and Education Network (NREN) in Uganda, through which universities access broadband connectivity in the country.

RENU's network shown in Figure 7 consists of a combination of its own dark fibre and a managed bandwidth backbone at speeds of 10 and 20 Gbps in Metro Kampala and 1 Gbps for access links. It has 6 Points of Presence (PoPs) and 10 Mini PoPs or aggregation sites distributed across the country.

Source: RENU, 2020

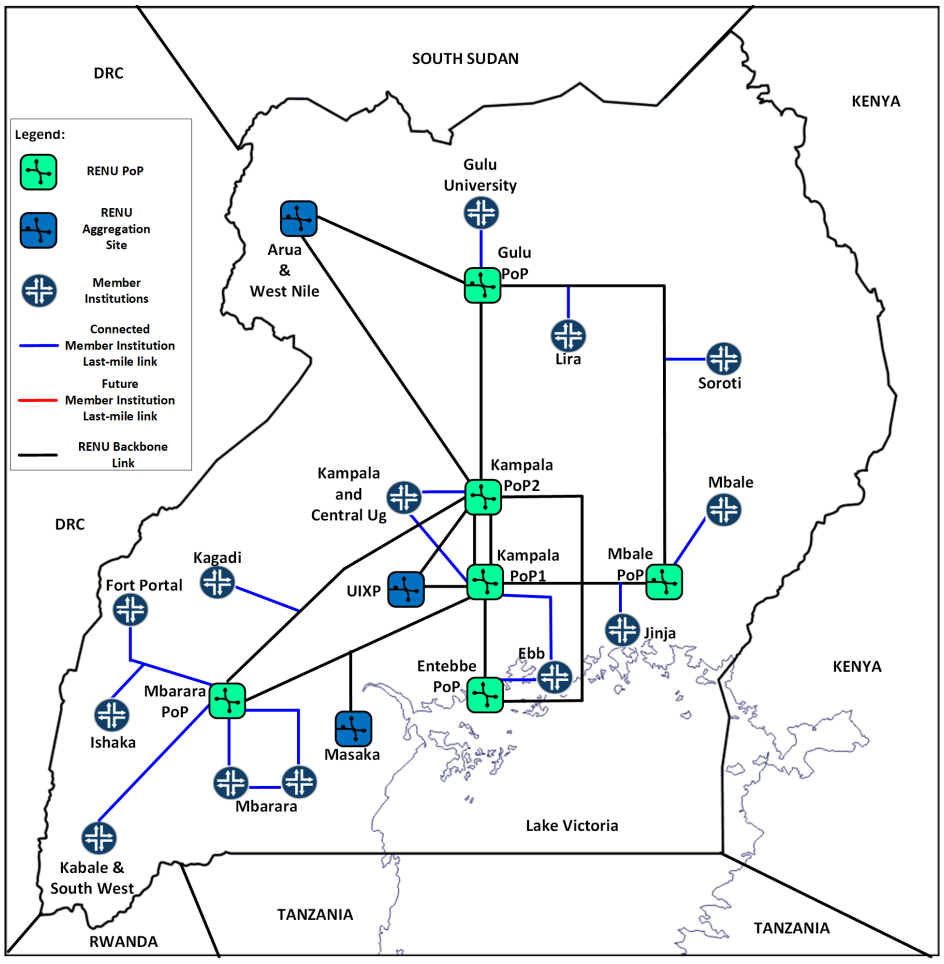


Figure 7: RENU Network

53 *http://renu.ac.ug/*

Some key highlights on RENU's operational processes and network infrastructure include:

i. Network connections had grown from one university site in 2012 to 204 sites across 30 Universities and 16 TVETs in 2020. Other connected institutions include 57 research institutions, 7 teaching hospitals, 52 secondary schools and 28 institutions affiliated with the education sector.

ii. Of the 204 sites, 97% are connected via fibre, while 3% are connected via microwave fixed wireless technology.

iii. The total amount of bandwidth procured by RENU has grown from 68 Mbps in 2012 to 6 Gbps in 2020. Conversely, the retail unit price of bandwidth has fallen from about USD 650 (per Mbps/month) in 2012 to about USD 8 (per Mbps/month) in 2020.

iv. RENU charges members a cost that varies between $10-$50 per Mbps/month depending on the volume of bandwidth that a member procures (see Table 9).

Table 9: RENU's tier pricing variations based on the amount of bandwidth procured

Capacity (Mbps)	US$/Mbps/month
1 – 99	50
100 – 399	40
400 – 999	30
1,000 – 4,999	20
5,000+	10
Shared Capacity (Minimum 2 – Maximum 10)	108 (total per month)

Source: RENU, 2020

v. RENU's biggest consumer in terms of bandwidth at the moment is Makerere University, which receives 2.02 Gbps. With a projected enrolment of 36,477 students, this works out at 55.4 Mbps @ 1,000 students. This is still far below the progressive bandwidth target of 200 Mbps @1,000 students in 2020 or the 2 Gbps @ 1000 students in 2025.

vi. RENU generates 99% of its funding from the sale of bandwidth and 1% from providing advanced NREN services.

vii. RENU has collaborated with Roke Telkom,[54] a commercial provider to make eduroam accessible off-campus on Roke's metro Wi-Fi network covering Kampala, Entebbe and Mukono, to help university students and staff access learning and research resources remotely from their homes during the Covid-19 pandemic.[55]

viii. Uganda Communications Commission (UCC), the communications sector regulator, is piloting government-funded schools onto the NREN network as part of the Rural Communications Development Fund Project.

54 *Roke Telkom, https://www.roketelkom.co.ug*
55 *https://renu.ac.ug/assets/docs/eduroam-press-release.pdf*

B.4 UbuntuNet Alliance

The UbuntuNet is a regional backbone network that interconnects NRENs in Eastern and Southern Africa and connects them to other regional networks worldwide. The network shown in Figure 8, which currently covers 15 member NRENs, is managed and operated by the UbuntuNet Alliance,[56] a regional association of NRENs with a secretariat based in Lilongwe, Malawi.

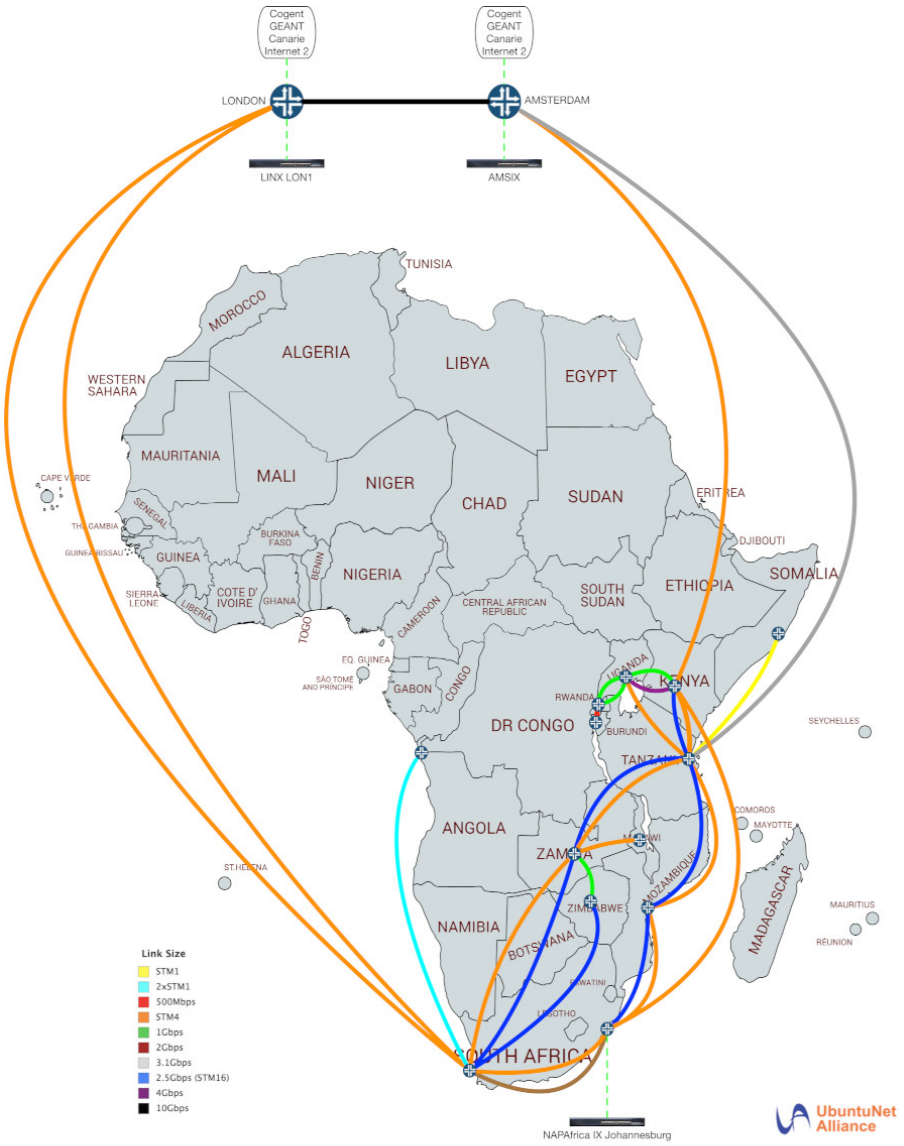


Figure 8: Schematic map showing UbuntuNet network

56 *https://ubuntunet.net/*

i. UA provides Regional REN connectivity, allowing member NRENs to exchange traffic with each other over the UbuntuNet regional REN backbone. The capacity of links across the network varies from an STM1 (155 Mbps) to 10 Gbps.

ii. UA delivers bandwidth (Global Transit in Africa) to member NRENs at in-country Points of Presence (PoPs). UA's biggest consumers for Global Transit in Africa include MoRENet at 4.3 Gbps, followed by RENU at 4 Gbps and ZAMREN at 2 Gbps.

iii. Advanced member NRENs can also peer with UA at PoPs in London and Amsterdam (Global transit in Europe). KENET is the biggest NREN in this category, procuring 20 Gbps of transit at the UA PoP in London.

iv. Table 10 uses projected higher education enrolment and current bandwidth provided by UA to calculate the projected bandwidth per 1000 students across selected NRENs. It shows how far NRENs in Africa have to go before they can reach par with their counterparts in other parts of the world.

v. The total amount of bandwidth provided to NRENs by UA has grown from 835 Mbps in 2012 to 11.5 Gbps in 2020.

vi. UA charges members a cost that varies between $5-$35 per Mbps/month depending on the country's location and local market conditions.

Table 10: Bandwidth capacity procured by selected NRENs from UA (ranked)

NREN (Country)	Bandwidth Capacity (Gbps)	Projected higher education enrolment (2021)	Projected bandwidth 2021 (Mbps@1000)
MAREN (Malawi)	1.8	43,000	41.9
KENET (Kenya)	20.0	1,126,000	17.8
MoRENet (Mozambique)	4.3	248,000	17.3
ZARNET (Zimbabwe)	3.6	263,000	13.7
RENU (Uganda)	4.0	294,000	13.6
ZAMREN (Zambia)	2.0	162,000	12.3
BERNET (Burundi)	0.5	49,000	10.2
RwEdNet (Rwanda)	0.6	64,000	9.4
TERNET (Tanzania)	0.5	201,000	2.5
SomaliREN (Somalia)	0.2	250,000	0.8
Eb@le (DRC)	0.3	588,000	0.5

Source: UbuntuNet Alliance

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