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NSF Program(s): International Research Network Connections

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Executive Summary

The AARCLight project has continued its work over this reporting period to develop critical components to revolutionizing U.S. collaboration with the African continent via a South Atlantic submarine cable connection, the first in production. AARCLight has created a critical mass of connectivity by signing contracts with funding outside this proposal for spectrum between the U.S. and Luanda, Angola that will last until 2032 or the life of the cable. AARCLight has fostered critical research collaborations with the nascent and established African regional network consortiums- WACREN and UbuntuNet (section 5.1). AARCLight has developed a critical connection in partnership with TENET, operator of the South African NREN, to extend 100G connectivity from Angola to South and on to East Africa via the open exchange point in Cape Town. AARCLight has further strengthened the partnership with RNP and ANSP to ensure Brazilian collaboration in the operation and the development of U.S.-Brazil-Africa network connectivity, most notably the new South American Exchange point (SAX) in Fortaleza.

Both Monet and SACS submarine cable systems achieved Ready-for-Service state during this reporting period (section 5.2). This interconnectivity from the U.S. to Africa via Brazil in a seamless submarine solution is approaching readiness for the Research and Education networking community in 2019. The timeframe and the flexibility to light at whatever technology is currently available, provides a baseline for planning the next generation of collaborations and major instruments, safe in the understanding that there will be efficient, available, and unmediated connectivity between the continents.

AARCLight has continued its efforts in forging research collaborations that will link the U.S. to the research and education communities in the nations of Africa. This strategic priority with Africa offers research and education communities with unique biological, environmental, geological, anthropological, and cultural resources. Research challenges in atmospheric and geosciences, materials sciences, tropical diseases, biology, and other disciplines will benefit by enhancing the technological and social connections between the research and education communities of the US and Africa. Astronomy continues to grow in scientific importance to US researchers with observatories located in South Africa. The Square Kilometer Array (SKA) construction and first light is publicly planned for 2022, while the first antenna was lit in the Fall of 2018. Just as LSST in Chile is a pathfinder project for the US's IRNC Backbone project for Latin America, so too will SKA act in that capacity to build out robust redundant network paths between S. Africa and the US. Section 7 offers an updated science drivers' section in this years' report.

We anticipated that a delay of a year between the planning and an implementation project could result in loosing valuable momentum gained thus far, which has resulted in the application and granting of a no cost extension until December 2019 for AARCLight. We propose that the most effective action is to develop and submit a full five-year project proposal for AARCLight to commence in January 2020. In the interim, a request for a supplement to support salary and travel for the AARCLight team will be forthcoming.

1 Project Participants

1.1 People

Julio Ibarra, Principal Investigator, focuses on managing the procurement, provisioning, network engineering, budgets and fiscal operations, and support of the AARCLight project. Interfaces with U.S. and international research and education backbone networks, coordinating project management and oversight activities with the NSF. Provides overall leadership and planning for the AARCLight project and chair the AARCLight Steering Committee.

Heidi Morgan, Co-Principal Investigator, is the Research Coordinator, working with application communities to ensure effective utilization of the network resources. Responsibilities include working with science groups to document their utilization of the network, and forecast future demand. She coordinates application specific key personnel.

Donald A Cox, Co-Principal Investigator, is the AARCLight Project Manager, and responsible for day-to-day operations of the infrastructure. His responsibilities include coordinating network operations, deployment, and upgrades, ensuring availability of network resources, coordinating technology transfer to providers, and developing new operations models for AARCLight.

Luis Lopez, Co-Principal Investigator, is the Engineering Coordinator and responsible for effective communication and coordination among the engineering managers and the AARCLight Engineering Committee (AEC).

1.2 International Organizations

UbuntuNet Alliance is a regional research and education network in eastern and southern Africa, that works with its member NRENs, and coordinates and collaborates with peer regional R&E networks, such as GEANT and RedCLARA. The UbuntuNet Alliance seeks to extend the capacity and resilience of its broadband research and education backbone network - UbuntuNet - with high-speed connections to NRENs worldwide and the Internet.

TENET: The Tertiary Education and Research Network of South Africa is South Africa's national research and education network organization. TENET operates the South African National Research Network (SANReN). South Africa does not have single NREN organization. SANReN and TENET jointly form South Africa's NREN.

SANReN: The South African National Research Network (SANReN) is a business unit inside the South African CSIR's Meraka Institute and is responsible for the design, acquisition and roll-out of national and international capacity for the South Africa NREN, as well as the development and incubation of advanced services. SANReN is a key component of the South African government's National Integrated Cyberinfrastructure System (NICIS), alongside the Centre for High Performance Computing (CHPC) and the Data Intensive Research Initiative of South Africa

(DIRISA).

SABEN: South African Broadband Education Networks (SABEN) is a non-profit company that connects schools networks and the Technical and Vocational Education and Training (TVET) sector in South Africa to SANReN. SABEN is supported by TENET and SANReN to assist colleges self-fund connections to the NRENs and aggregate traffic from schools, hospitals, libraries, hosting, VOIP and video conferencing services.

West and Central African Research and Education Network (WACREN) is a regional research and education network serving the West and Central African Research and Education community for its development.

Academic Network of São Paulo (ANSP, Brazil) provides connectivity to the top R&E institutions, facilities and researchers in the State of São Paulo, that links 20 research institutions in the State of São Paulo in Brazil; and GridUNESP, one of the largest computational clusters in Latin America, supporting interdisciplinary grid-based science.

Rede Nacional de Ensino e Pesquisa (RNP, Brazil): RNP operates the national research and education network in Brazil, consisting of a national backbone network, 40 dark fiber-based metropolitan networks in major cities, and other access links, providing high-capacity access to more than 1,200 sites, serving all the best research groups in the country, as well as large national laboratories and data centers in HPC, Synchrotron Light, Biodiversity, Agricultural Sciences and e-Health.

CLARA: CLARA is the Latin American Regional R&E network in Latin America, providing access to national R&E networks in the region, connecting them to the global academic Internet.

1.3 US Collaborators

Florida LambdaRail (FLR): FLR is the regional optical network of Florida, formed as a consortium of Florida's research universities, to support their research and education mission.

Internet2: I2 is a consortium of leading US research universities working in partnership with industry and government to develop and deploy advanced network applications and technologies. Internet2 is the representative for MAN LAN, participating in the AtlanticWave project.

2 Background

Florida International University and AmLight consortium partners are planning, designing, and defining a strategy for high capacity connectivity research and education network connectivity between the US and West Africa, called AARCLight: Americas Africa Research and eduCation Lightpaths. Science is being conducted in an era of information abundance. Sharing science resources, such as data, instrumentation, technology, and best practices, across national borders, can promote expanded scientific inquiry and has the potential to advance discovery. Linking the U.S. and the nations of Africa's researcher and education communities is an increasingly strategic priority. Africa offers research and education communities with unique biological, environmental, geological, anthropological, and cultural resources. Research challenges in atmospheric and geosciences, materials sciences, tropical diseases, biology, astronomy, and other disciplines will

benefit by enhancing the technological and social connections between the research and education communities of the US and Africa.

The planning project is largely based on the planned availability of submarine cable spectrum for use by research and education communities. It creates an unprecedented opportunity for the stakeholders in the U.S., Africa, and Brazil to coordinate planning efforts to strategically make use of the offered spectrum towards serving the broadest communities of interest in research and education. The AmLight consortium partners are the (Brazilian Education and Research Network (RNP), Academic Network of São Paulo (ANSP), Latin American Cooperation of Advanced Networks (CLARA), Chile's Red Universitaria Nacional (REUNA), Florida LambdaRail (FLR), Association of Universities for Research in Astronomy (AURA), and Latin American Nautilus.

3 Major goals of AARCLight project for year 2

The major goals of AARCLight project for year 1 are the following:

- Investigation of an Open Exchange point in West Africa
- Develop a new network design in collaboration with AARCLight partners
- Develop additional goals and strategies to expand the scope of work based on findings from years 1 and 2 activities
- Develop an assessment plan for the following objectives: the engagement level of the community of interest, the spectrum contracts, the shared vision and goals by the AARCLight partners, and the level of engagement with the potential new infrastructure
- Develop a plan for community engagement

4 Major Activities/Milestones for the AARCLight Project Year 2

This section describes the accomplishments of the AARCLight team for year 2. The section is organized by the goals of the project. The goals have been further refined based on our findings.

4.1 Goal 1: Investigation of an Open Exchange point in West Africa & Other Connectivity Options

4.1.1 Survey AARCLight Partners & Assess findings

Previously, we were solely focused on determining if the formation of an open exchange point in Luanda, where the South Atlantic Cable System (SACS) African cable landing is located, would provide strategic value to the R&E community. Over the last year it became clear that an alternative option was both of interest and more practical in the near term. The alternative of collaborating with S. Africa to swap capacity on their West African Cable System (WACS) link with our SACS link was both attractive, and feasible through network engineering based on the proximity of WACS to SACS.

When the proposal was accepted as a planning grant by NSF, we set out to gauge the broad enthusiasm and collaboration of R&E network operators in Africa and S. America, particularly Brazil. Through our work in meetings and conference attendance, it became clear that the regional networks in Africa and Brazil were quite enthusiastic and the meaning of "AARCLight partners" was more finely defined to include AmLight-ExP, RNP, and TENET.

Led by Co-PI Morgan, we participated in several online meetings with representatives from Brazil and South Africa via BlueJeans. Consensus was reached to submit a white paper abstract to the Ubuntunet-Connect 2018 Conference scheduled over the U.S. Thanksgiving holiday this year. Participants of the meetings included: Julio Ibarra, Jeronimo Bezerra, and Vasilka Chergarova (Research Coordinator) from FIU, Luis Fernandez Lopez (Co-PI: AARCLight, Director of ANSP Brazil), , Chip Cox (Co- PI: AARCLight, Vanderbilt University), Gabriella E. Alvarez (PhD candiate Harvard-Smithsonian Center for Astrophysics), Michael Stanton (Network Scientist, RNP Brazil), Aluizio Hazin (Engineering RNP Brazil), Len Lotz (Executive Officer, TENET South Africa), and Siju Mammen (Head of Network Engineering, SANReN South Africa). The meetings resulted in our abstract acceptance and a collaborative publication presented at the conference in Zanzibar, Tanzania.

Morgan presented the white paper “AARCLight – New opportunities for South Atlantic R&E Network collaboration between Africa, Brazil, and the U.S.”. See Appendix C for details. Together with the FIU research coordinator and participation by TENET and NREN operators throughout Africa, we conducted a qualitative study with the following areas of discussion:

1. Measure interest and need to enhance fast network access to R&E network connectors in S. America and the U.S.
2. Discuss network design options for each NREN
3. Learn more about the data intensive science disciplines in each country
4. Develop a case study on these communities of interest
5. Encourage participants to participate in our NREN operators survey

To determine the preferences and assess next steps with our collaborating partners, a survey for African R&E Network Operators was developed. The survey was introduced in conjunction with the UbuntuNet-Connect 2018 conference in collaboration with the conference organizer. The survey methodology combined qualitative interviews and a quantitative online survey (See Appendix A). The goal of the survey was to further assess the interest of the African NREN operators to strategically make use of the capacity of a S. Atlantic connection. We focused on gathering data to serve the broadest communities of interest in research and education. A summary of the study is described in Appendix B.

4.1.2 Evolution of S. Atlantic Network Infrastructure

Several existing and new cable systems are interconnecting the continents in the South Atlantic as shown in Figure 1. The MONET cable connecting Boca Raton and Miami, Florida (USA) to Fortaleza (Brazil) is operational. Through other projects, including AMPATH and AtlanticWave SDX, we have begun provisioning a point-of-presence (PoP) in the Equinix MI3 facility in Boca, which is where MONET terminates in the US, and a terrestrial connection to MI1 (NAP of the Americas) in Miami. The 6,165km South Atlantic Cable System (SACS) between Fortaleza to Sangano (Angola) was completed in Q3 2018 [1] and is operational. SACS is 100% owned and managed by Angola Cables (AC).

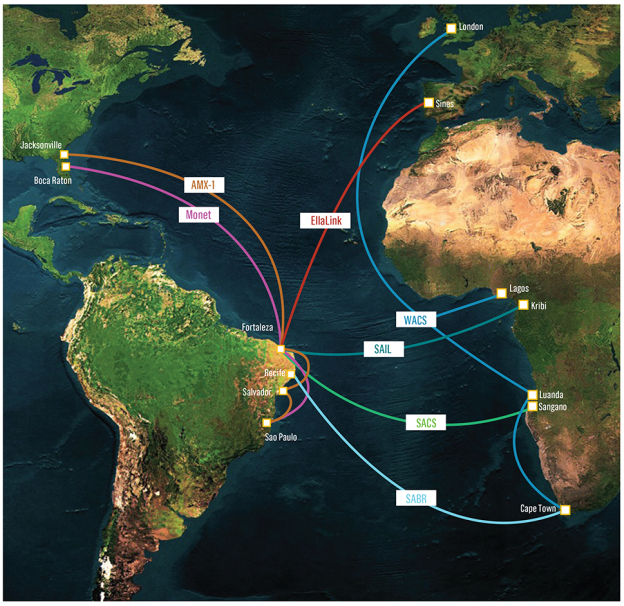


Figure 1 Submarine cables in the South Atlantic

As previously reported, FIU has an agreement with AC for effectively 100 Gbps of capacity provisioned over spectrum using coherent WDM technology. SACS offers a total design capacity of 40 Tbit/s between Fortaleza and Luanda.

In September 2018 the South Atlantic Inter Link (SAIL), connecting Fortaleza to Kribi, Cameroon was also completed.

The EllaLink cable midpoint was announced in December as Praia, capital of Cabo Verde. Eventually it is expected that EllaLink [2] [3] will build out the cable to Fortaleza and aims to be Ready For Service (RFS) in 2020. Cabo Verde sits off the coast of West Africa roughly halfway between the planned endpoints in Sines, Portugal and Fortaleza and Praia Grande, Brazil.

The 17,500km America Movil (AMX-1) cable system, from Fortaleza to Jacksonville and Hollywood, FL has been operational since 2015 [4]. AMX-1 has multiple landing points in Colombia, Brazil, the Dominican Republic, Puerto Rico, Guatemala, Mexico, and the United States. Seaborn's SABR cable system [5] is currently being developed to connect Cape Town to Recife, Brazil, and eventually the USA and will be RFS in 2029. **Fortaleza is a landing point for all these cables, except for SABR.**

In June 2018, network performance tests were made (Table 3) from Cape Town to Latin America and the U.S., which shows quantified improvement over the new SACS and MONET cable systems via the S. Atlantic. The current latency data was provided by TENET over the UbuntuNet, GEANT and Internet2 links. The *Estimated via SACS* column shows improved performance using data collected from the Angola Cables IP network. The *Possible Improvement* column shows the percentage of the estimated improvement, ranging from 20% to 71% in reduced latency.

Table 1 Estimated performance improvement using SACS cable system

From Cape Town to:	Currently via TENET, UbuntuNet, GEANT, and I2 *	Estimated via SACS	Possible Improvement
New York	241ms	192ms	20%
Miami	272ms	161ms	41%
Fortaleza, Brazil	336ms	97ms	71%
Sao Paulo, Brazil	381ms	142ms	63%
Santiago, Chile	382ms	183ms	52%
La Serena, Chile	392ms	193ms	51%

* Data column 2 provided by TENET/Len Lotz June 2018, except NY. All else from Angola Cables

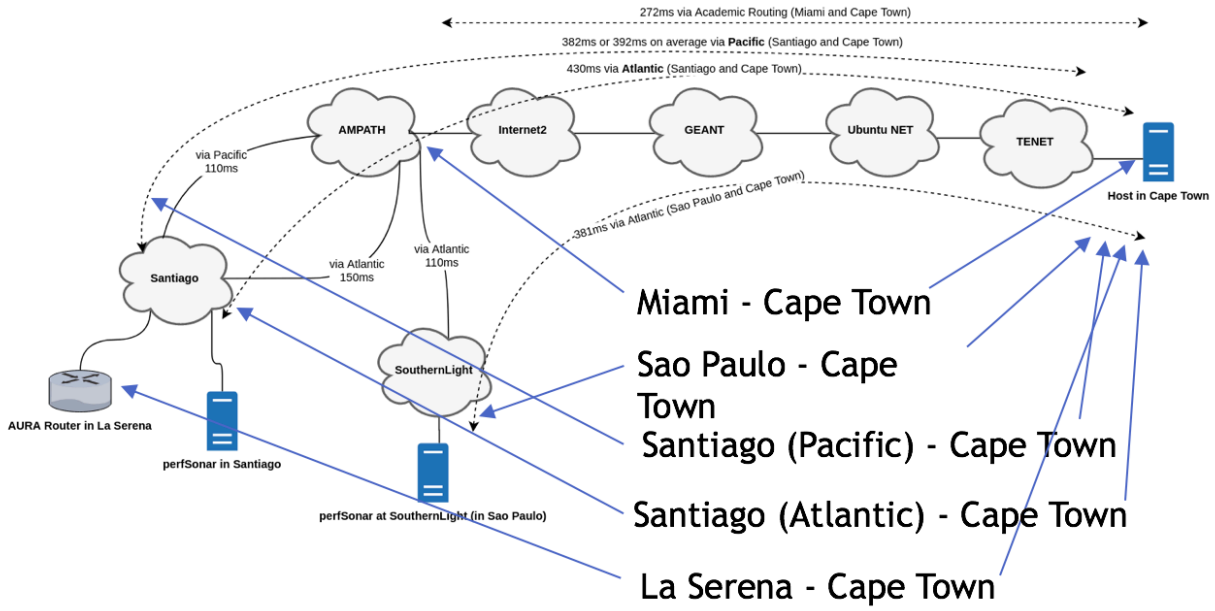


Figure 2 Conceptual network diagram of the tested network path

Figure 2 shows the conceptual network diagram of the domains involved in the tested path.

4.1.3 New GOLE/GXP in Fortaleza: South Atlantic Crossroads (SAX)

The South Atlantic Crossroads (SAX) is a new academic exchange point, managed by RNP [5][6] in Fortaleza, Brazil. SAX connects to many PoPs within Brazil. In addition, RNP participates in the Global R&E Networks CEO Forum, and in particular in the planning of the Global Network Architecture (GNA) [7], which seeks to provide a rational global R&E network infrastructure. The GNA team has already identified Fortaleza as a critical point in the future design of this global network, due to its location at the narrowest part of the South Atlantic Ocean, thus providing an optimal location for exchanging traffic between Europe, Africa, and the Americas. Having the connectivity coming from Sao Paulo, Florida and Angola in Fortaleza allows R&E networks from South America to collaborate with partners in Africa with significantly less delay, (at least 150ms lower) than using the current paths available. High resolution video

and big data applications will benefit from the establishment of the SAX international exchange point in Fortaleza. An opportunity for using spectrum to reach continental US (via MONET), African R&E researchers could collaborate with partners in Brazil and the U.S., also with reduced delay, at least 100ms lower, compared to the current paths available.

SAX is designed to be compliant with both GNA and Global Lambda Integrated Facility (GLIF) initiatives. GLIF is an international consortium that promotes the interconnection of lambdas around the world. GLIF International lambdas act as an integrated facility with the goal to support data-intensive scientific research. Since 2005, via conferences and workshops, GLIF gathers the data from discussions about equipment, requirements for connections, and essential engineering functions and services [8]. International partners, such as RedCLARA, AmLight ExP and GEANT, are crucial to providing the new circuits reaching SAX.

4.1.4 African stakeholders interested in facilitating the S. Atlantic Link

South African National Research & Educational Networks: The Tertiary Education and Research Network of South Africa (TENET) is South Africa's national research and education network organization. TENET operates the South African National Research Network (SANReN). SANReN and TENET jointly form South Africa's NREN (SA NREN) and operates an exchange point in Cape Town called ZAOXI. SA NREN has ownership of 7.4% of the WACS cable allowing it to light capacity between any 2 landing stations. AARCLight and AmLight are forming a collaborative partnership with SA NREN. The UbuntuNet Alliance can participate in this project through its connection in Cape Town. Additionally, UbuntuNet can participate by helping to establish an Exchange Point in Luanda. SA NREN can light capacity between ZAOXI and the new exchange point using WACS. Collaborative partners can utilize capacity as needed on the SACS cable, WACS cable, AARCLight etc. to connect to AmLight in Fortaleza, ZAOXI in Cape Town or any other connected Exchange point. SA NREN's WACS connectivity may be extended to reach other landing stations to add new collaborative partners to the project.

4.1.5 Opportunity for a new R&E Exchange point at Luanda, Angola

With two submarine systems (WACS and SACS) with landing stations in Angola (Figure 4), an open exchange point in Luanda would act as a catalyst for revolutionary change in the Angolan research and education community. Currently, the universities all procure only commodity Internet connectivity. A task force has been organized to develop and build out an Angolan National Research and Education Network. Viable NRENs in West Africa are part of the focus of the European Union's AfricaConnect2 and AfricaConnect3 projects. As such, an open exchange point in Luanda could become a point of interconnection with WACREN. Furthermore, through both the 2010 MOU between Internet2 and UbuntuNet Alliance, as well as the UbuntuNet Alliance strategic plan, fostering interconnectivity between the U.S. research and education networking communities and those of UbuntuNet is considered to be mutually desirable.

The AARCLight project is developing the plan for the first direct R&E networking physical infrastructure to support the long-standing desire for furthering Africa, Brazil, US network-enabled collaboration. AARCLight constitutes more than an incremental change in the infrastructure enabling collaboration. It is a technological tipping point that will enable the U.S., Brazil, Angola, WACREN, UbuntuNet Alliance, SaNREN, and TENET to exponentially increase the rate of collaboration, discovery, and learning.

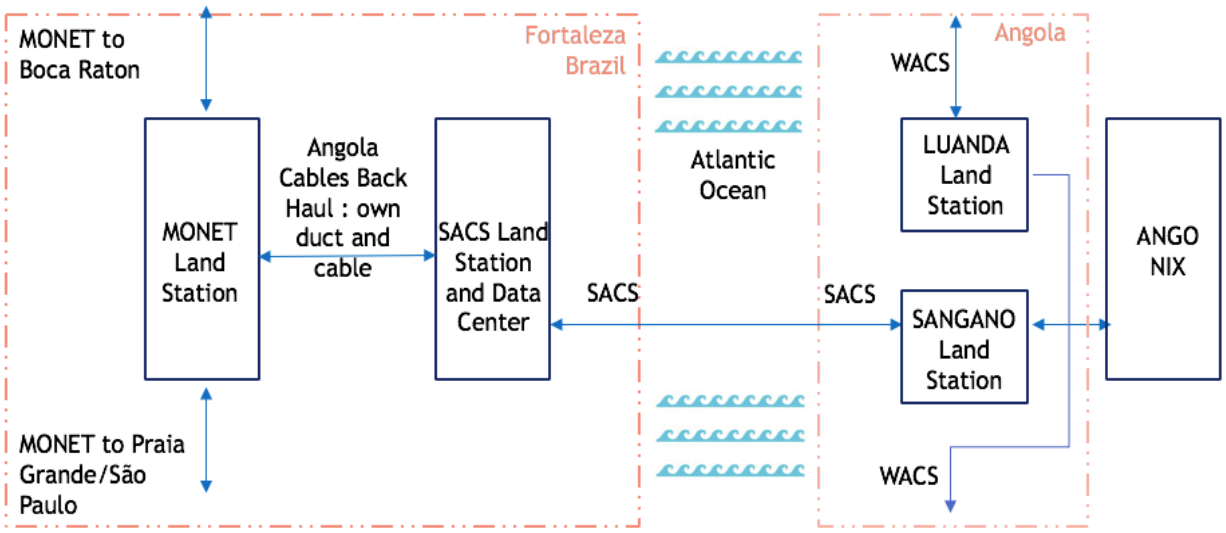


Figure 3 Updated Logical diagram of landing station of SACS and WACS cable systems in Angola

Several discussions with representatives from the African Regional NRENs, WACREN (CTO Omo Oaiya) and UbuntuNet Alliance (CEO Pascal Hoba), showed enthusiasm for future collaboration between Africa, Brazil and the USA.

4.2 Goal 2: Develop a new network design in collaboration with AARCLight partners

4.2.1 A New Network Design Connecting the U.S. to West Africa Via S. Atlantic

AARCLight partners developed a network design that can fully leverage the SACS and MONET submarine cable systems spectrum allocation. The AmLight-ExP DWDM design (Figure 5) was created to activate MONET subsea system using CIENA Waveserver Ai chassis installed at PoPs in Boca Raton (MI-3), and Fortaleza (FORT AC-DC) and Sao Paulo (SP-3 and SP-4) in Brazil. The AARCLight and MONET connections will share the same datacenter, and, the same CIENA Waveserver Ai chassis to connect to South Atlantic Crossroads (SAX) exchange point switching fabric. SAX is designed to be compliant with both GNA and GLIF Open Exchange initiatives and international partners, such as CLARA, AmLight-ExP and GEANT, whom will terminate their circuits on SAX to enable efficient data sharing across all participants. The SAX switching fabric is being designed to use Juniper MX10008 routers (blue box on Figure 5), capable of connecting multiple 100G interfaces.

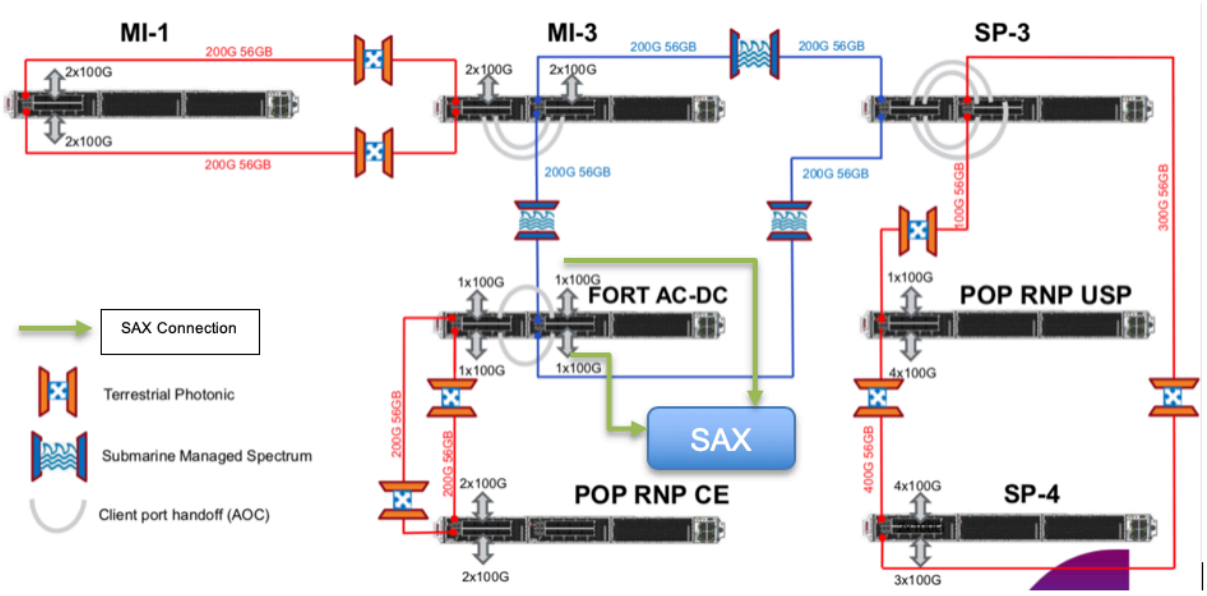


Figure 4 AmLight DWDM design to support SAX, MONET, and AARCLight

The new network design responds to the question of ***how spectrum shall be used on the operational SACS cable?*** Spectrum shall be used to support the collaborative projects between the U.S., Brazil, and Africa. The spectrum could provide capacity bandwidth to a future exchange point in Angola. It will connect to the Cape Town exchange point and provide capacity to UbuntuNet Alliance partners. Discussion is currently underway with WACREN and the NEAR project to determine the feasibility of a connection in Lagos. TENET is willing to facilitate this connection to WACS in Lagos, thereby providing capacity to WACREN partners.

4.2.2 Representation and description of connectivity to U.S.

Table 4 below shows the current African RENs participating in the regional networks (UbuntuNet Alliance, WACREN, and ASREN). As noted in Table 3 above, the latency improvement by using the S. Atlantic route over SACS has the potential to markedly improve R&E network performance between Africa and South and North America.

Table 2 Current African RENs members by Regional Networks

Regional Network Organization	Participating RENs	
UbubntuNet Alliance covers the Eastern and Southern regions of Africa along with the Oceanic countries in the regionNet Alliance	BERNET	RwEdNet
	Eb@le	SomaliREN
	EthERNet	SudREN
	i RENALA	TENET
	KENET	TERNET
	MAREN	Xnet
	MoRENet	ZAMREN
	RENU	ZARNet & ZIMREN
WACREN - the regional REN of West and Central Africa	Ghana: GARNET	Sierra Leone: SLREN
	Côte d'Ivoire : RITER	Burkina Faso: FasoREN

	Togo: TogoRER Niger : NigerREN Nigeria: NgREN Cameroun: RIC Mali: MaliREN Chad: TchadREN Guinea: Gn-REN	Ghana: GhREN France: RENATER Nigeria: Eko-Konnect Senegal: snRER Gabon: GabonREN Benin: RerBenin
ASREN – the regional REN that covers North Africa and the Middle East	Algeria Bahrain Comoros Djibouti Egypt Iraq Jordan Kuwait Lebanon Libya Mauritania	Morocco Oman Palestine Qatar Saudi Arabia Somalia Sudan Syria Tunisia United Arab Emirates Yemen

4.3 Goal 3: Develop additional goals and strategies

As the second year of AARCLight concludes our immediate next steps to affect the above described connection are clear. The personnel, network engineering, equipment and services required have been partially defined in this report and will be expanded during the third year of AARCLight. We will document the project plan to report to the NSF. This expanded project plan shall be grounded on the findings and recommendations from year 1 and 2 activities.

Last year we set the milestone of exploring the feasibility of submitting a new five-year proposal to the NSF and other country partner funding agencies, and we believe we are now ready to move forward. We have thus far presented a clear and coherent articulation describing how to use the new networking capacity in the near term towards solutions, in collaboration with community-of-interest participants and early adopters.

In year 2, the AARCLight PIs and partners in Africa and Brazil continued working together to articulate a strategy towards the effective use of the proposed network capacity on the SACS submarine cable system. This section provides an update of the strategy.

The strategy that is being discussed takes into consideration the established and planned infrastructures of each of the partners:

- SA NREN operates an open exchange point in Cape Town and has capacity on the WACS submarine cable system.

- WACREN operates an open exchange point in Lagos that connects to London on a 10G link.
- FIU has contracted 37.5GHz of spectrum capacity on the SACS cable, and 225GHz of spectrum capacity on Monet from Angola Cables.
- RNP has nearly completed building an open exchange point in Fortaleza in conjunction with AmLight-ExP that connects to Angola Cables to establish connectivity to both SACS and MONET submarine cables. From Fortaleza, there is connectivity to both AmLight Express and Protect services.
- RNP will extend connectivity from Fortaleza to Sao Paulo to provide connectivity to both AmLight Express and Protect Services, and connectivity to ANSP and redCLARA.

Our new partner, TENET, which operates the SA NREN and the open exchange point in Cape Town is in process of signing an MoU with FIU to effectively trade capacity on WACS to enable SA NREN and Ubuntunet Alliance members to connect to SACS in Luanda.

4.3.1 Challenges

1. Fostering successful multi-national research collaborations between the U.S. and African nations is an ongoing challenge requiring personnel and travel support. Some steps to take include;

- In collaboration with AARCLight partners, leverage mechanisms between NSF and African funding agencies to develop proposals that will support student exchange and project specific workshops.
- Possible mechanisms are international programs NSF offers (e.g., Early-concept Grants for Exploratory Research (EAGER), and the International Research Experiences for Students (IRES)) in coordination with peer African funding agencies.

2. Sign MoU agreements with Ubuntunet Alliance and WACREN leadership
- WACREN is poised to enter into a letter of intent to be followed by an MoU with AARCLight via FIU
- Ubuntunet Alliance CEO gave his verbal agreement to enter into an MoU with AARCLight; however, the incumbent is outside of his contract period and a new CEO is to be named. We will have to restart talks once the new CEO is known.

3. Determine long term funding sources for personnel, travel, equipment & maintenance, and smart hands in Luanda.

4.4 Goal 4: Develop an assessment plan

4.4.1 Qualitative study to assess collaborative partners

To determine the preferences and assess next steps with our collaborating partners, a survey for African R&E Network Operators was developed. The survey was introduced in conjunction with the UbuntuNet-Connect 2018 conference in collaboration with the conference organizer. The survey methodology combined qualitative interviews and a quantitative online survey (See Appendix A). The goal of the survey was to further assess the interest of the African NREN operators to strategically make use of the capacity of a S. Atlantic connection. We focused on

gathering data to serve the broadest communities of interest in research and education. A summary of the study is described in Appendix B.

4.5 Goal 5: Develop an Expanded Plan of Community Engagement

4.5.1 Face-to-Face Connections

Conferences, meetings, workshops and other relevant venues attended by representatives of the NREN and science application communities are important for AARCLight members to attend. While much can be done virtually with established colleagues, the personal meetings before and during these collaborations cement the participants commitment and common ground.

During 2018, AARCLight PI, Co-PIs, and senior personnel continued attending relevant venues in Africa and the U.S. attended by representatives of the NREN and science application communities. PI Ibarra participated at the WACREN 2018 Conference in Lomé, Togo on 15-16 March.

At the IRNC PI Meeting at the Internet2 Global Summit in San Diego, CA, Ibarra presented Americas Africa Research and eduCation Lightpaths (AARCLight) Study findings for year one, AtlanticWave-SDX, and current status and future goals for the AmLight Express and Protect (AmLight-ExP) projects.

Co-PI Morgan convened a side meeting of the attending African NRENs and regional networks at the I2 Global Summit where preliminary understanding of the AARCLight project's readiness to light the SACS cable and develop active partnerships was discussed. In attendance were PI Ibarra, Chief Network Engineer Bezerra (AARCLight), Luis Lopez (ANESP), Lourino Chemane (Morenet), Omo Oaiya (WACREN, Len Lotz (SANREN) and others.

PI Ibarra presented the updates in the AARCLight project, "Regional Networks, Communities, and Ecosystems Americas Africa Research and eduCation Lightpaths (AARCLight) Study: Year 1 findings" at the TERENA Network Conference (TNC18) held in Trondheim, Norway.

4.5.2 Continue Engaging Communities of Interest in Africa, N. & S. America

The AARCLight project team will mark this as a milestone to further develop during the coming year. For example, CANARIE (Canada's NREN) is a strategic partner for SKA (regional data center) and could be a strategic partner for AARCLight.

4.6 Summary of Accomplishments in Year 2

This section summarizes the accomplishments described above as follows:

- Investigation of an Open Exchange point in West Africa and Other Connectivity Options
    - Surveyed AARCLight partners to determine if it's of strategic value to the R&E community to establish an open exchange point in Angola
    - Documented the results of the survey into a report from the AARCLight consortium to the NSF and African stakeholders
- Developed a new network design in collaboration with AARCLight partners
    - Developed a new network design using data from the achievements of earlier goals
    - The new network design responds to the operational support questions (still under development), and includes representation and description of connectivity to U.S.

- Developed additional goals and strategies to expand the scope of work based on findings from years 1 and 2 activities
    - Challenges are described including additional funding for personnel, travel, equipment, maintenance, etc.
- Developed a plan for community engagement
    - Conferences, meetings, workshops presence
    - Continue engaging communities of interest

4.7 Significant results for Year 2

This section describes research projects of the major science drivers by discipline in Africa during the past year. The information was gathered from several sources and partners.

Multiple ongoing collaborative projects between the researchers from the U.S., Brazil and African communities can potentially benefit from the network connections in the South Atlantic. Here we are presenting only a few of the major projects involving cyberinfrastructure, astronomy, medical, agricultural and genomics research.

4.7.1 Advanced Cyber Infrastructure (ACI)

PI Ibarra is maintaining a collaborative relationship with Elizabeth Leake (STEM-Trek Nonprofit), who reported on the updates of the current HPC ecosystem development in Africa (Table 5). Additionally, reported in Michael Foley's "Framing a Case for NRENs in the Longest Last Mile" opening keynote speach at the South African Centre for High Performance Computing National Conference (CHPC2018) on Tuesday, December 4. See extract below:

> *The price of fiber is high in many regions and continues to be a financial stumbling block. The World Bank supported NREN development in Somalia via the AfricaConnect2 program and the next-generation project, AfricaConnect3 (2018-2020), was just announced. This program has allocated 37.5 million euros to improve connectivity among African nations and European collaborators. The US National Science Foundation (NSF) supported the NEAAR Project, based at Indiana University, which will improve the pipeline between the U.S. and Africa via GÉANT. As for capacity-building, Foley credits the Network Startup Resource Center (NSRC) at the University of Oregon-U.S. With 25-years of experience in network skills development, NSRC has vastly improved the global network workforce pipeline. NSRC can also help universities upgrade switches and routers. "An NREN is only as good as its last mile," said Foley.*

As the lead Distance Learning Specialist at the World Bank in Washington DC in the United States (US) from 1997 until 2015, Foley's work focused on all aspects of the development of the Global Development Learning Network. Now that he's retired, he has more time to pursue his passion for photography, but remains engaged with NREN advocacy on behalf of underserved regions.

Table 5 Updated African HPC Ecosystems project sites/NREN status

#	African HPC Ecosystems	NREN	Region Membership	Status	Op. Level	eduGAIN
1	Botswana	No	UbuntuNet S/No	Planning	2	no
2	Ethiopia	EthERNet	UbuntuNet E/Yes	Operational	4.5	no
3	Ghana	GARNET	No	Unknown	Unknown	Unknown

4	Kenya	KENET	UbuntuNet E/Yes	Operational	6	applying via EUGRIDPMA
5	Madagascar	iRENALA	UbuntuNet Yes	Operational	4	no
6	Malawi	MAREN	UbuntuNet Yes	Operational	Unknown	Applied
7	Mauritius	No	UbuntuNet/No	Planning	2	no
8	Mozambique	MoRENet	UbuntuNet S/Yes	Operational	5.5	Yes
9	Namibia	Xnet	UbuntuNet S/Yes	Operational	4	no
10	South Africa	SANREN	UbuntuNet E/Yes	Operational	6	yes, via SAFIRE
11	Uganda	RENU	UbuntuNet (?)	Operational	Unknown	yes
12	Zambia	ZAMREN	UbuntuNet S/Yes	Operational	5	Yes, via FIDERN

*Update from a chart published by Elizabeth Leake (STEM-Trek) January 2017; based, in part, on a World Bank report by Michael Foley (Role and Status of NRENS in Africa)
https://www.hpcwire.com/2018/01/11/uriscsc17-and-the-longestlastmile/

4.7.2 Astronomy Sciences (AST)

The South African Astronomical Observatory (SAAO) [9] is a facility of the National Research Foundation (NRF) [10], which operates optical telescopes, outreach and research located in Sutherland under the Department of Science and Technology. The Southern African Large Telescope (SALT) [11] is the largest single optical telescope in the southern hemisphere and among the largest in the world managed by SAAO. SALT is funded by a consortium of international partners from South Africa, the U.S., Germany, Poland, India, the U.K., and New Zealand. Other SAAO Hosted Research Telescopes are BiSON [12], KELT-South [13], LCOGT [14], MONET [15], Solaris [16], SuperWASP-South [17].

The MeerKAT [18] 64-antenna array radio telescope located in the Karoo region is a precursor to the Square Kilometre Array (SKA) [19] and will be merged into the SKA1 (2020) with current data at a rate of 4.7 Gbps. SKA High frequency dishes will produce ten times the current global internet traffic and generate 960,000 Tb/day with rate of ~160 Gb/s. SKA will be the largest array telescope in the southern hemisphere (2024) with collaborators from USA, Canada, India, Japan, China, Australia, France, UK, Italy, Finland, Germany. SKA Phase two will include telescopes from New Zealand, Botswana, Ghana, Kenya, Mauritius, Madagascar, Mozambique, Namibia and Zambia.

4.7.3 Biological Sciences (BIO)

Brazilian Research and Educational Network (RNP) applications: RNP supports many science drivers complimentary to collaboration with African research interests. An agricultural collaborative research involving pest control on army worm (*lagarta do cartucho*) attacking maize and sorghum, is conducted between Brazil, U.S., South Africa, and nine other African countries and supported by Embrapa (Brazilian Corporation for Agricultural Research in the Ministry of Agriculture). Multiple ongoing collaborative medical projects with the African nations of the Community of Portuguese -Speaking Countries (CPLP) are established by the Brazilian Ministry of Health - Osvaldo Cruz Institute (FIOCRUZ) in collaborations with the National Institute of Infectiology in Mozambique on clinical research and clinical tests. CPLP consists of the following countries: African countries: Angola, Cape Verde, Equatorial Guinea, Guinea-Bissau, Mozambique, and São Tomé and Príncipe. Non-African full members: Brazil, Portugal, and Timor-Leste. The scope of those projects includes infectious diseases, such as Malaria, STI, AIDS, Viral Hepatitis, and Tuberculosis. Another FIOCRUZ and Federal University of Rio de Janeiro (UFRJ) project in Angola is collaborating with the National Institute for Health Research (NIHR) of the

Angolan Ministry of Health de Angola, currently investigating the genotyping and resistance of HIV-1 to anti-retroviral drugs.

The Atlantic International Research Centre (AIR-Centre) has agreements between the EU-BR-ZA for collaborative research activities in the South Atlantic and Southern Oceans
The ambition of the AIR Centre is to be a long-term platform for North-South, South-North, East-West and West-East collaboration in the Atlantic towards a holistic, integrative and systemic approach to knowledge on space, oceans, climate change impacts, energy and data sciences, while fostering an inclusive perspective to science, technology and economic development [20].

MoRENeT (Mozambique NREN has a long-standing collaboration with RNP participating annually in the RNP Forum since 2014. Activities include exchange of good practices in management and governance of research networks, IT training (including 25 techies in 2017 in Brazil), and exchange of information on technical and operational management.

4.7.4 Medical research

At the Internet2 Technology Exchange meeting, Dr. Julio Ibarra met with Christopher Whalen, International Program Manager at Office of Cyber Infrastructure and Computational Biology National Institute of Allergy and Infectious Diseases, NIH. Several NIH major collaborative projects are identified in the area of infectious disease control and prevention in Africa.

Project Title	Multidisciplinary Research for Malaria Control and Prevention in West Africa
Institution	Lead Institution: University of Sciences, Tech & Tech of Bamako, Bamako; Principal Investigator: Seydou Doumbia, M.D., Ph.D.
Summary	The overall goal of this ICEMR is to understand the variable effectiveness of current malaria control interventions in different ecological settings of West Africa. This goal will be accomplished by performing field and laboratory studies of the epidemiology, entomology (transmission), immunology and pathogenesis of malaria to characterize and understand: 1) The heterogeneity of malaria infection, disease and transmission, 2) The effects of control strategies on malaria transmission and pathogenesis, 3) The major obstacles to improving malaria control and potentially eliminating malaria, including drug and insecticide resistance
Collaborators	Project Leads: Nafomon Sogoba, University of Sciences, Techniques, and Technology of Bamako Mahamadou Diakite, University of Sciences, Techniques, and Technology of Bamako Sekou Fantamad Traore, University of Sciences, Techniques, and Technology of Bamako Collaborating Institutions: Tulane University, New Orleans, LA University of Georgia, Athens, GA University of Miami, Miami, FLA London School of Hygiene and Tropical Medicine, London, UK University of Copenhagen, Denmark Wellcome Trust Sanger Institute, Hinxton Cambridge, UK Malaria Immunology Section, Laboratory of Malaria and Vector Research, NIAID

Project Title	Malaria Transmission and the Impact of Control Efforts in Southern and Central Africa
Institution	Lead Institution: Johns Hopkins Bloomberg School of Public Health, Baltimore; Principal Investigator: William Moss, M.D., M.P.H.
Summary	The overall goal of the Southern and Central Africa ICEMR is to study the barriers to malaria control and elimination in Southern and Central Africa. The ICEMR will examine factors contributing to sustained malaria infections in high, moderate and low transmission settings. This goal will be achieved through a combination of: 1) State-of-the-art research on malaria epidemiology, vector biology, and the genetics of the malaria parasite in three different epidemiological settings in southern and central Africa, 2) Collaborations with national malaria control programs to develop locally-adapted control strategies, 3) Training, career development, and capacity building at research institutions in Zambia, Zimbabwe and the Democratic Republic of the Congo.
Collaborators	Project Leads: William Moss, Johns Hopkins Bloomberg School of Public Health Douglas Norris, Johns Hopkins Bloomberg School of Public Health Jennifer Stevenson, Johns Hopkins Bloomberg School of Public Health Collaborating Institutions: Macha Research Trust, Macha, Zambia Biomedical Research and Training Institute, Harare, Zimbabwe Tropical Diseases Research Centre, Ndola, Zambia University of the Witwatersrand, Johannesburg, South Africa National Institutes of Health Research, Harare, Zimbabwe Université Protestante au Congo, Kinshasa, Democratic Republic of Congo University of North Carolina-Chapel Hill, Chapel Hill, North Carolina University of Massachusetts Medical School, Boston, Massachusetts
Project Title	Program for Resistance, Immunology, Surveillance & Modeling of Malaria in Uganda (PRISM)
Institution	Lead Institution: University of California, San Francisco; Principal Investigator: Grant Dorsey, M.D.
Summary	This program called "PRISM" is based in Uganda and represents the East African region for the International Centers of Excellence for Malaria Research network. Uganda is emblematic of the challenges faced by high burden countries, where routine surveillance systems are inadequate to assess trends in the burden of malaria or to monitor the impact of control interventions. Through PRISM researchers have implemented a comprehensive malaria surveillance program including enhanced health facility-based surveillance and detailed longitudinal studies with differing transmission intensities. Complementary laboratory-based studies include surveillance for markers of antimalarial drug and insecticide resistance and serologic measures of malaria exposure.

Collaborators	Project Leads: Epidemiology: Moses R. Kamya, Makerere University and Infectious Diseases Research Collaboration (IDRC), Uganda Resistance: Samuel Nsobya, Makerere University and IDRC, Uganda Transmission: Sarah Staedke, London School of Hygiene and Tropical Medicine, U.K. Collaborating Institutions: Infectious Diseases Research Collaboration (IDRC), Kampala, Uganda Makerere University College of Health Sciences, Kampala, Uganda Liverpool School of Tropical Medicine, Liverpool, UK London School of Hygiene and Tropical Medicine, London, UK Radboud Institute for Health Sciences, Netherlands Stanford University, Stanford, CA Durham University, Durham, UK Institute for Health Metrics and Evaluation, Seattle, WA
Project Title	The Intransigence of Malaria in Malawi: Understanding Hidden Reservoirs, Successful Vectors and Prevention Failures
Institution	Lead Institution: Michigan State University, East Lansing; Co-Principal Investigators: Terrie Taylor, D.O. and Don Mathanga, M.D., M.P.H.
Summary	The primary objectives of research supported by the Malawi ICEMR are to identify, understand, and evaluate interventions that target the determinants of malaria disease. The Center aims to identify reasons why malaria in Malawi has remained resistant to usual control measures. Researchers will accomplish these objectives by systematically surveying populations of vectors, hosts, and parasites using newly developed molecular and genomic tools in conjunction with well-established epidemiologic approaches.
Collaborators	Project Leads: Miriam Laufer, Division of Malaria Research, Institute of Global Health, University of Maryland School of Medicine Don Mathanga, Malaria Alert Centre, University of Malawi College of Medicine Karl Seydel, College of Osteopathic Medicine, Michigan State University Collaborating Institutions: University of Malawi College of Medicine, Blantyre, Malawi University of Maryland School of Medicine, Baltimore MD University of Michigan, Ann Arbor MI Malawi-Liverpool-Wellcome Trust Clinical Research Programme, Blantyre, Malawi
Project Title	Environmental Modifications in Sub-Saharan Africa: Changing Epidemiology, Transmission and Pathogenesis of Plasmodium falciparum and P. vivax Malaria
Institution	Lead Institution: University of California, Irvine; Principal Investigator: Guiyun Yan, Ph.D.

Summary	The overarching goal of this ICEMR project is to assess the impact of human-induced environmental modifications such as dam construction, irrigation and shifting agricultural practices on the epidemiology, transmission, pathogenesis and immunology of Plasmodium falciparum and P. vivax malaria in highly populated Kenya and Ethiopia where major investments in water resource development projects are taking place.
Collaborators	Project Leads: Ming-Chieh Lee, University of California, Irvine Guiyun Yan, University of California, Irvine James Kazura, Case Western Reserve University, Cleveland Collaborating Institutions: Addis Ababa University, Addis Ababa, Ethiopia Burnet Institute, Melbourne, Australia Case Western Reserve University, Cleveland Jimma University, Jimma, Ethiopia Kenya Medical Research Institute, Kismu, Kenya

In addition to those projects, NIH HIV/AIDS clinical trial projects are involved with several trial network groups that are identified in the USA and Africa.

Project Title	NIH HIV/AIDS Clinical Trials Networks
Institution	AIDS Clinical Trials Group (ACTG) HIV Prevention Trials Network (HPTN) HIV Vaccine Trials Network (HVTN) International Maternal Pediatric Adolescent AIDS Clinical Trials group (IMPAACT) Microbicide Trials Network (MTN)
Summary	In 2006 these clinical trials networks were restructured to better address emerging domestic and international challenges to developing improved HIV treatment and prevention strategies by creating a more integrated, collaborative and flexible research structure. The HIV/AIDS clinical trials Networks funded by the Division of AIDS (DAIDS) of the U.S. National Institutes of Health (NIH)
Collaborators	U.S. Military HIV Research Program (USMHRP) Centers for Disease Control and Prevention (CDC) Comprehensive International Program of Research on AIDS (CIPRA) Global Campaign for Microbicides (GCM) The Dale and Betty Bumpers Vaccine Research Center (VRC) Center for HIV/AIDS Vaccine Immunology (CHAVI) International AIDS Vaccine Alliance (IAVI) Collaboration for AIDS Vaccine Discovery (CAVD) Partnership for AIDS Vaccine Evaluation (PAVE)

There are many NIH sponsored projects all over Africa that are dependent on connectivity for data transfers back to the U.S.. These transfers are becoming more substantial as the use of genomic data and imaging data becomes more widespread. We are continuing to gather information about individual projects and should have more precise information during 2019.

The United States Army Medical Research Directorate Kenya (USAMRD-K) is another collaborative initiative between NIH and African medical research communities. USAMRU-K is located in Nairobi, Kenya on the campus of the Kenya Medical Research Institute (KEMRI) and is one of five U.S. DoD overseas research laboratories. The USAMRU-K Kisumu Field Station is based in Kisumu, Kenya located in Nyanza Province along Lake Victoria. There are five clinic and research departments to include Clinical Trials, Basic Science, Malaria Diagnostics Center (MDC), Entomology/Vector Biology Unit, and Malaria Drug Resistance (MDR) Laboratory. The focus of this program is to develop drugs and vaccines for malaria and other tropical diseases.

Project Title	Malaria Drug Resistance (MDR)
Institution	Malaria Drug Resistance (MDR) laboratory
Summary	The Malaria Drug Resistance (MDR) laboratory conducts comprehensive surveillance of antimalarial drug resistance throughout Kenya through in vitro susceptibility testing, in vivo efficacy studies, and genetic analysis of Plasmodium falciparum populations. MDR's efforts provide invaluable epidemiological data, which directly supports the scientific objectives of KEMRI/USAMRD-K and its partners and provides timely information to the U.S. Department of Defense and Kenya Ministry of Health in order for these agencies to make informed malaria policy decisions. MDR is comprised of three sections, the in vitro parasite culture laboratory, in vivo efficacy laboratory, and the molecular genetics and bioinformatics laboratory, and has a staff of one uniformed service officer, one medical officer, one doctoral level scientist, three master's level scientists, five laboratory technicians, and four graduate students
Collaborators	U.S. Department of Defense and Kenya Ministry of Health
Project Title	Entomology Program/Vector Biology
Institution	Kisian KEMRI-campus in Kenya
Summary	The Entomology Program/Vector Biology Unit conducts research on the biology and ecology of vectors of medical and military important diseases with a focus on the development of integrated disease surveillance and management strategies. This department is based on the Kisian KEMRI-campus in western Kenya. Additionally, the Entomology program has six remote field collection sites located in Marigat, Kakamega, Busia, West Pokot, Garissa, Wajir, Isiolo, and Lamu. Future field collection sites will be established in Tanzania, Ethiopia, and Uganda. The goals of the Entomology program are to develop products, tools, and methods to mitigate risk and/or prevent vector-borne diseases.
Collaborators	U.S. Department of Defense, US Military Academy, USUHS Military Tropical Medicine, Kenya Ministry of Health
Project Title	Malaria Diagnostics Centre (MDC)
Institution	Malaria Diagnostics Centre (MDC), a department of the KEMRI/USAMRD-K located in Kisumu, Kenya

Summary	Malaria Diagnostics Centre (MDC), a department of the KEMRI/USAMRD-K located in Kisumu, Kenya is the largest malaria diagnostic center in sub-Saharan Africa. The MDC was established in 2004 to conduct malaria diagnostic training. The center leads the global effort in training to improve malaria diagnostics capacity and quality at laboratories in Kenya, across Africa, Europe, Asia, South America, and the United States. Malaria microscopy remains the gold standard for malaria diagnosis in clinical trials, new diagnostic methodology evaluation and clinical care. Due to its location in a highly malaria endemic region of Kenya, MDC has the advantage of having a continuous supply of samples for human malaria parasites through its Blood Collection Protocol (BCP). These samples are used for preparation of blood films that are stored in its slide bank; these slides are used for training and testing laboratory technicians, developing and managing malaria quality assurance programs; they are also available to other institutions upon request. The samples collected are also used for testing of novel diagnostic devices and assays.
Collaborators	Malaria Clinical Trials Alliance (MCTA), European Developing Countries Clinical Trial Partnership (EDCTP), AIDS Clinical Trial Group (ACTG), Sanofi Aventis, Kenya, Africa, Europe, Asia, South America, the United States, Nigeria, Tanzania, and Ghana.
Project Title	Basic Science Lab
Institution	USAMRD-K Basic Science laboratory
Summary	Supports USAMRU-D's broader mission of health security by: – Providing disease surveillance and assisting in outbreak investigations for infectious diseases of military and global health relevance – Supporting development of diagnostic platforms for diseases of Africa and the world – Providing basic science support to vaccines and drug trials evaluations – Building capacity for young Kenyans in various areas including molecular biology and immunology
Collaborators	U.S. Government: US DOD GEIS – USAMRIID, MIDRP – US CDC Kenya Government: Kenya Medical Research Institute, MOH, Department of Veterinary Services, Academia , International and NGO. PATH: BioFire, SMEs, MBIO Diagnostic, Boulder CO, SIGHT Diagnostics, Israel
Project Title	Clinical Trials
Institution	Muriithi-Wellde Clinical Research Center (CRC)
Summary	The Muriithi-Wellde Clinical Research Center (CRC), established in 2003, is located in Kombewa, approximately 40km from the Kisumu Field Station (USAMRD-K) Headquarters in Kondele in western Kenya. USAMRD-K has been operating in partnership for over 40 years with the Kenya Medical Research Institute (KEMRI), conducting research studies focused on malaria vaccines, anti-malarial drugs, supplements and diagnostics. The CRC is involved in both medical research and clinical care. The clinical care includes PEPFAR, clinical care provided in conjunction with all medical research, Demographic Surveillance Survey (DSS) Mapping and capacity building throughout the district. The CRC has a catchment

	population of ~150,000-200,000K, with a presence in over 20 Ministry of Health (MOH) Health Centers.
Collaborators	Kenya Medical Research Institute (KEMRI), U.S. Department of Defense, Kenya Ministry of Health

The KEMRI Welcome Trust Research Program (KWTRP) is based within the KEMRI Centre for Geographic Medical Research. The core activities are funded by the Welcome Trust and include conducting integrated epidemiological, social, laboratory and clinical research in parallel, with results feeding into local and international health policy. This research platform includes state-of-the-art laboratories, a demographic surveillance system covering a quarter of a million residents, partnership with Kilifi County Hospital in health care and hospital surveillance, a clinical trials facility, a vibrant community engagement program and a dedicated training facility.

Project Title	KEMRI-Wellcome Trust Research
Institution	KEMRI Centre for Geographic Medicine Research-Coast as one of the KEMRI center's in Kenya
Summary	Conducting integrated epidemiological, social, laboratory and clinical research in parallel, with results feeding into local and international health policy.
Collaborators	Kenya Medical Research Institute Wellcome Trust Charity The University of Oxford and Warwick Kilifi County Government Nairobi County Government Ministry of Health Kenya Mbale Regional Referral Hospital in collaboration with Busitema University Liverpool School of Tropical Medicine London School of Hygiene and Tropical Medicine Imperial College Institute of Child Health in London

4.8 Key outcomes or Other achievements for the year 2

This section describes the inception of the relationships among the PI & Co-PI, and the key researchers and scientists involved in projects that are taking place in Africa.

During year 2, the AARCLight PI and Co-PI visited African countries to investigate the opportunities for international collaboration (Togo and Tanzania). All sites expressed interest in collaborating with us.

Co-PI Morgan met with researchers from South African Universities and representatives from SANReN, TENET, UbuntuNet Alliance, and WACREN:

- Pascal Hoba - UbuntuNet Alliance
- Lourino Alberto Chemane - MoRENEt
- Barry Boubakar - CEO WACREN
- Abdullahi Bihi Hussein - SomaliREN
- Magreth Mushi - Tanzania REN
- Regina Mboma - Tanzania REN
- Alex Mwotil - Uganda REN
- Omo Okaiya WACREN
- Len Lotz - TENET/SANReN

Co-PI Ibarra met with representatives from UbuntuNet Alliance, WACREN, GEANT, NEEAR project PI, the President of the UbuntuNet Board of Directors.

Additional information about science drivers is gathered via the ongoing AARCLight project research survey. The 11th UbuntuNet Connect conference in Zanzibar, Tanzania created an opportunity to assess the e-cyberinfrastructure of the participating African NRENs. Responses from the CEOs, Senior Managers, and other African NREN representatives expressed a lot of enthusiasm in engaging in collaborative research between the U.S., Brazil, and the African communities using the increased capacity via the SACS network connection opportunity in the South Atlantic. See below extract of email received from the Lourino Chemane, CEO of MoRENet:

Lourino A. Chemane <lourino.chemane@morenet.ac.mz> Thu, Nov 15, 2018 at 1:51 AM
To: "Heidi L. Morgan" <drheidi@mac.com>
Cc: Vasilka Vassi Chergarova <vchergar@fiu.edu>, Julio Ibarra <je_ibarra@mac.com>, Michael Stanton <michael@rnp.br>, "Lourino A. Chemane" <lourino.chemane@morenet.ac.mz>, lourino chemane <lourino.chemane@mctestp.gov.mz>, clementina mataveia <clementina.mataveia@gmail.com>, Clementina Mataveia <clementina.mataveia@morenet.ac.mz>

Dear Heidi Morgan,

Thanks for the message and for your interest in meeting MoRENet representatives.

I am will be attending UbuntuNet Conference 2018 in Zanzibar and available to meet and discuss with important issues and challenges included in your email.

Just to share with you our efforts to have MoRENet ready for the Angola Cable submarine fiber optic cable and the AARCLight project.we are in our final stage of the negotiation and contracting of a 10 Gbps link from Maputo to Cape Town to get closer to the WACS and Angola Cable Capacity, putting us in a good position for research collaboration projects between the US and Africa as part of the AARCLight project. It is not an easy exercise for us both from the technical and financial point of views but we are doing our best to have MoRENet and the Mozambique Research and Education community to be part of these international developments.

We do have a very good collaboration with RNP, the Brazilian NREN, and we have been following up the developments of the AARCLight project and its potenctial opportunities for African NRENs and for MoRENet in particular. We are doing the same with SANREN (TENET) and UbuntuNet.

We can agree on the best date and time to meet in Zanzibar.

Regards

Lourino Chemane

5 Opportunities for training and professional development

Training and professional development has not been provided in year 2; however, we have discussed workshop opportunities with the African REN leadership and will continue to develop these ideas during 2019.

6 Products and Outreach Activities

Section 7 reports on products and outreach activities achieved in year 2.

6.1 Conferences Papers and Presentations (delivered in year 2)

Section 7.1 describes conference presentations that were delivered in year 2 of the project.

6.1.1 WACREN 2018 Conference in Lomé, Togo, 15-16 March 2018

Dr. Julio Ibarra participated at the WACREN 2018 Conference in Lomé, Togo on 15-16 March 2018, which focused on catalyzing quality higher education and research.
The main theme of the conference is: "WACREN – Unleashing Potentials", with the following sub-themes:

- Advanced Network Technologies and Services (SDN, Cloud services, mobility services, NOCaaS, …)
- Building and Strengthening User Communities (research communities, librarians, etc.)
- NREN Business Models and Use Cases – Experiences Around the World

The conference is organized in a special context: the rollout of the WACREN network, with the promise of dramatically changing the IT landscape in higher education and research in the region.
For the conference program click here.

6.1.2 Internet2 Global Summit, San Diego, CA, May 6-9, 2018

AmLight Team presented Americas Africa Research and eduCation Lightpaths (AARCLight) Study findings for year one, AtlanticWave-SDX, and current status and future goals for the AmLight Express and Protect (AmLight-ExP) projects at the IRNC PI Meeting at the Internet2 Global Summit. The 2018 Internet2 Global Summit, co-hosted by CENIC, University of California San Diego and San Diego State University, featured keynote addresses from top R&E leaders, presentations from noted experts, and sessions focused on advanced and trusted infrastructure, identity, federation and access management, and solutions for researchers with the goal of benefiting the entire research and education ecosystem.

6.1.3 TERENA Network Conference (TNC18) - Trondheim, Norway, June 10-14, 2018

The AmLight Team presented "AmLight's SDN Looking Glass – An SDN centralized monitoring system" and updates on the "Regional Networks, Communities, and Ecosystems Americas Africa Research and eduCation Lightpaths (AARCLight) Study: Year 1 findings" at the TERENA Network Conference (TNC18), held in Trondheim, Norway. TNC18 focused on a variety of thought-provoking sub-themes such as the power of the Internet, the responsibility of sustainability and delivery, the power of data analytics, the creation of intelligent complexity, and networking at the speed of science.

The TNC18, the 34th edition, was hosted by Uninett. Uninett develops and operates the Norwegian national research and education network, interconnecting about 200 Norwegian

educational and research institutions and more than 300,000 users, as well as giving them access to international research networks. TNC is the largest and most prestigious European research networking conference, with more than 650 participants attending this annual event. It brings together decision makers, managers, networking and collaboration specialists, plus identity and access management experts from all major European networking and research organizations, universities, worldwide sister institutions, as well as many industry representatives. Through keynotes, speeches by renowned specialists, varying parallel sessions, demonstrations and presentations, TNC presents participants with a unique overview of the latest developments in research networking, both in the technical field and in the area of application and management.

For AmLight presentation video recording click here.
For AARCLight video recording click here.
For more details about the TNC18 click here.

6.1.4 Computing in High Energy and Nuclear Physics (CHEP 2018) Conference, Sofia, Bulgaria, July 9-13, 2018

Jeronimo Bezerra, CIARA Assistant IT Director, and Beraldo Leal, researcher of UNESP's Scientific Computing Center (NCC) presented "Using Kytos SDN platform to enhance international big data transfers" at the Computing in High Energy and Nuclear Physics (CHEP 2018) Conference which took place on 9-13 July 2018 at the National Palace of Culture, Sofia, Bulgaria. The conference was organized by the Institute for Advanced Physical Studies, Sofia University, Plovdiv University, New Bulgarian University, Bourgas Free University, INRNE-BAS, IICT-BAS and Sofia Municipality. Approximately 600 computing experts and scientists attended CHEP 2018.

Kytos SDN Open Source platform is a tool that has been developed by the Sprace (Sao Paulo Research and Analysis Center) engineers and researchers in partnership with AmLight to provide a simple and efficient solution for managing software-defined networks.
The CHEP conference addressed the computing, networking and software issues for the world's leading data-intensive science experiments that currently analyze hundreds of petabytes of data using worldwide computing resources. The Conference is a major event in the area, featuring plenary sessions, parallel sections, and poster presentations; it publishes peer-reviewed Proceedings. CHEP 2018 addressed challenges in data-intensive experimental and computational science to stress the increasing importance of the computing-related connections between high-energy and nuclear physics and data-intensive astronomy, X-ray science and computational science.

During the conference Leal and Bezerra, introduced the Kytos SDN Platform and showed how their latest application (Kytos MEF E-Line) can automate the process of creating WAN circuits. AmLight engineers are working on Kytos and MEF E-Line development in order to use this application for the provisioning and circuit management that will be used during experiments like LSST (The Large Synoptic Survey Telescope).

Details about the conference can be found here.
The paper abstract can be found here.
The presentation can be found here.

6.1.5 Supercomputing Conference (SC18), Dallas TX, November 11-16, 2018

Dr. Julio Ibarra, Jeronimo Bezerra, and Adil Zahir attended the Supercomputing Conference in Dallas Texas. During the conference. The AmLight Team was involved in multiple demonstrations:

NRE-16: Global Petascale to Exascale Science Workflows Accelerated by Next Generation SDN Architectures and Applications
Location: Booth 1413

Demonstrated were several major advances in software defined and Terabit/sec networks, intelligent global operations and monitoring systems, workflow optimization methodologies with real-time analytics, and state of the art long distance data transfer methods and tools and server designs, to meet the challenges faced by leading edge data intensive experimental programs in high energy physics, astrophysics, climate science including the Large Hadron Collider (LHC), the Large Synoptic Space Telescope (LSST), the Linac Coherent Light Source (LCLS II), the Earth System Grid Federation and others. Several of the SC18 demonstrations included a fundamentally new concept of "consistent network operations," where stable load balanced high throughput workflows crossing optimally chosen network paths, up to preset high water marks to accommodate other traffic, provided by autonomous site-resident services dynamically interacting with network-resident services, in response to demands from the science programs' principal data distribution and management systems. This was empowered by end-to-end SDN methods extending all the way to autoconfigured Data Transfer Nodes (DTNs), including intent-based networking APIs combined with transfer applications such as Caltech's open source TCP based FDT, which have been shown to match 100G long distance paths at wire speed in production networks. During the demos, the data flows were steered across regional, continental and transoceanic wide area networks through the orchestration software and controllers, and automated virtualization software stacks developed in the SENSE, PRP, AmLight, Kytos and other collaborating projects. The DTNs employed used the latest high throughput SSDs and flow control methods at the edges such as FireQoS and/or Open vSwitch, complemented by NVMe over fabric installations in some locations.

Download the final NRE-16 demo submission (PDF):
https://sc18.supercomputing.org/app/uploads/2018/11/SC18-NRE-016.pdf

NRE-17: Large Synoptic Survey Telescope (LSST) Real Time Low Latency Transfers for Scientific Processing Demonstrations

At SC18 in Dallas, Texas we experimented with data transfer rates, using 100Gig FIONA Data Transfer Nodes (a.k.a. DTNs) in Chile and Illinois. The demos aimed to achieve three goals: First, to demonstrate real time low latency transfers for scientific processing of multi-Gigabyte images from the LSST base station site in La Serena, Chile, flowing over the REUNA Chilean National Research & Education Network (NREN), as well as ANSP and RNP Brazilian national circuits and the AmLight-ExP Atlantic and Pacific Ring through AMPATH2 to Starlight and NCSA. Second, to simulate operational and data quality traffic to SLAC, Tucson and other sites including the Dallas show floor. Third, to stress test the AmLight ExP network to simulate the LSST annual multi-petabyte Data Release from NCSA to La Serena, at rates consistent with those required for LSST operations.

Download the final NRE-17 demo submission (PDF):
https://sc18.supercomputing.org/app/uploads/2018/11/SC18-NRE-017.pdf

NRE-18: Americas Lightpaths Express and Protect Enhances Infrastructure for Research and Education
Americas Lightpaths Express and Protect (AmLight ExP) enables research and education amongst the people of the Americas through the operation of production infrastructure for communication and collaboration between the U.S. and Western Hemisphere science and engineering research and education communities. AmLight ExP supports a hybrid network strategy that combines optical spectrum (Express) and leased capacity (Protect) that provides a reliable, leading-edge diverse network infrastructure for research and education.

Download the final NRE-18 demo submission (PDF):
https://sc18.supercomputing.org/app/uploads/2018/11/SC18-NRE-018.pdf

6.1.6 UbuntuNet-Connect Conference 2018 Zanzibar, Tanzania, 22-23 November 2018

Dr. Heidi Morgan presented the "*AARCLight – New opportunities for South Atlantic R&E Network collaboration between Africa, Brazil, and the U.S.*" at the UbuntuNet-Connect is the Annual Conference of UbuntuNet Alliance, that focused on research and education networking activities in Africa. It was organized by UbuntuNet Alliance and hosted by member NRENs. The Conference brought together practitioners in the research and education networking community, researchers, policy makers, academicians, connectivity providers, and a pool of expertise from across Africa and beyond. In previous years, the conference has attracted sponsorship from leading commercial companies and service providers.
This year UbuntuNet-Connect 2018, the 11th edition of the series of UbuntuNet-Connect conferences was held in Zanzibar and was hosted by the Tanzania Education and Research Network (TERNET), the NREN of Tanzania. The conference took place on 22-23 November 2018.
More details about the conference can be found here.
For the presentation click here.

See Appendix C for copy of the paper.

6.1.7 Websites

The AARCLight project web site is at http://aarclight.net/

7 Year 3 Goals and Milestones planning

The previous sections described the achievements in year 2. This section describes the goals and milestones for year 3 of the project. The major activities form the outline of this section, as in the previous section. Milestones are the actionable statements within the major activities.

7.1 Implement a SACS-WACS connection using the network design

7.2 Pursue supplemental funding in January 2019 and write a new five year proposal to support ongoing activities

7.3 Continue Engaging Communities of Interest

Participate in conferences, workshops and meetings with the established AARCLight partners and develop more formalized collaborative relationships

7.4 Science Drivers – Update and add new disciplines and / or projects

8 Impact

This section describes the impacts AARCLight achieved in year 2.

8.1 Impact on the development of the principal discipline(s) of the project

Novel spectrum implementation via a new network design

Opportunity to significantly reduce latency between Africa S & N America utilizing the S. Atlantic route

8.2 Impact on other disciplines

Opportunity to facilitate big data transfers to foster scientific and educational collaborations

8.3 Impact on development of human resources

Nothing to report

8.4 Impact on physical resources that form infrastructure

This is a physical cyberinfrastructure project which strives to provide significantly improved R&E network connectivity between Africa, the U.S., and Brazil in particular and three continents in general via a S. Atlantic connections.

8.5 Impact on institutional resources that form infrastructure

Nothing to report

8.6 Impact on information resources that form infrastructure

Information resources in the regions described have the potential for more robust support. We will report more on this in the 2019 annual report.

8.7 Impact on technology transfer

Nothing to report

8.8 Impact on society beyond science and technology

The AARCLight project has created several critical components to revolutionizing U.S. collaboration with the African continent. AARCLight has created a critical mass of connectivity by signing contracts with funding outside this proposal for spectrum between the U.S. and Luanda, Angola that could last 35 years. AARCLight has fostered critical research collaborations with the nascent and established African regional network consortiums-WACREN and UbuntuNet Alliance. AARCLight has developed a critical connection in partnership with SA NREN to extend 100G connectivity from Angola to South and on to East Africa. AARCLight has further strengthen the partnership with RNP and ANSP to ensure Brazilian collaboration in the operation and the development of U.S.-Brazil-Africa network connectivity.

AARCLight has created a critical mass of connectivity by entering into an unprecedented contract with Angola Cable to secure lifetime-of-the-cable access to unlit spectrum on both MONET and on SACS submarine cable systems. This provides a new rising tide that lifts the paths of interconnectivity from the U.S. to Africa in a seamless submarine solution. This time frame, and the flexibility to light at whatever technology is currently available, provides a baseline for planning the next generation of collaborations and major instruments, safe in the understanding that there will be efficient, available, and unmediated connectivity between the continents.

AARCLight has fostered critical research collaborations towards linking the U.S. to the research and education communities in the nations of Africa. This strategic priority with Africa offers research and education communities with unique biological, environmental, geological, anthropological, and cultural resources. Research challenges in atmospheric and geosciences, materials sciences, tropical diseases, biology, and other disciplines will benefit by enhancing the technological and social connections between the research and education communities of the US and Africa. Of striking scientific importance to US researchers are the astronomy projects located in South Africa, some of which will lead the way to the Square Kilometer Array (SKA) construction and first light planned for 2022. Just as LSST in Chile has been a pathfinder project for the US' IRNC Backbone project for Latin America, so too will SKA act in that capacity to build out robust redundant network paths between S. Africa and the US. This report Section 7 will detail the data requirements, researcher requirements, and collaborative opportunities to provide US researchers with the connectivity to enable them to lead astronomical scientific discovery from the SKA.

9 Changes / Problems

To move from an AARCLight planning grant to a production R&E network infrastructure new funding is needed. The exact nature of furthering this activity will be approached in two steps. First the PIs would like to request supplemental funding for calendar year 2019 and next, a new five-year proposal will be presented.

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Appendix A: Survey Questions

Survey questions used to gather qualitative data from Africans NRENs operators and their infrastructure at the UbuntuNet-Connect 2018 Conference in Zanzibar, Tanzania, on November 22-23, 2018. https://fiu.qualtrics.com/jfe/form/SV_1CcwpFrr72r5ZC5



1. Please enter your contact information below:
   (Veuillez entrer vos coordonnées ci-dessous:)

   Name (Prénom)
   Position
   Email
   Organization (Organization)
   Country (Pays)

2. What cyber e-infrastructure do you manage? Please include the network, HPC, and any science or online learning special services that are international in nature.
   (*Quelle cyber-infrastructure gérez-vous? Veuillez inclure le réseau, le HPC et toute science ou services spéciaux d'apprentissage en ligne de nature internationale.)*

3. Are you a member of: (select all that apply)
   (Êtes-vous membre de: (cochez toutes les réponses qui s'appliquent))

   WACREN
   UbuntuNet Alliance
   SANReN
   Others

4. What is the current bandwidth capacity of your network? Please address connection points and bandwidth for commodity Internet and / or Research & Education Networking.
   (Quelle est la capacité actuelle de votre réseau? Veuillez indiquer les points de connexion et la bande passante pour les réseaux Internet et / ou le réseau de recherche et d'éducation.)

5. How many research institutions does your network currently support? Please list the number of universities, laboratories, and other big data producing connectors.
   (Combien d'institutions de recherche votre réseau soutient-il actuellement? Veuillez indiquer le nombre d'universités, de laboratoires et d'autres connecteurs produisant des données volumineuses.)

6. Do you have a plan to connect more research organization in the near future? If yes, please describe the type of organizations and your timeline?
   (Avez-vous un plan pour connecter plus d'organisations de recherche dans un avenir proche? Si oui, veuillez décrire le type d'organisations et votre calendrier.)

7. Do you have collaboration in South & North America that will benefit from a South Atlantic research and education network connection? If yes, please describe the collaboration by Country, State, City, type of science and / or education, and other details that will help us facilitate an end-to-end high-performance network connection.
   (Avez-vous une collaboration en Amérique du Sud et du Nord qui bénéficiera d'une connexion au réseau de recherche et d'enseignement de l'Atlantique Sud? Si oui, veuillez décrire la collaboration par pays, État, ville, type de science et / ou d'éducation, ainsi que d'autres détails qui nous aideront à faciliter une connexion réseau de haute performance de bout en bout.)

8. Please describe how the connection in the South Atlantic route would bring benefits to your organization in addition to your answer in Q7 above, if any.
   (Veuillez décrire en quoi la connexion sur l'Atlantique Sud présente des avantages pour votre organisation, en plus de votre réponse au Q7 ci-dessus, le cas échéant.)

9. What challenges would your NREN face to access the bandwidth capacity on the new South Atlantic (SACS) cable?
   (Quels défis votre NREN devra-t-il relever pour accéder à la capacité en bande passante du nouveau câble (South Atlantic) SACS?)

10. Please add any other comments you may have below.
    (Veuillez ajouter tout autre commentaire que vous pourriez avoir ci-dessous.)

Appendix B: Qualitative Study

African NREN Operators inquired in the AARCLight study:

Name	Institution	Country	Email
Aina Adeola Alain Patrick	WACREN CTO	Benin	alain.aina@wacren.net
Osro Behailu Korma	Education Strategy Center (ESC)	Ethiopia	behailu.korma@yahoo.com
Yousef Shaker Ahmad Altorman	Managing Director ASREN	Jordan	torman@asrenorg.net
Joy Oyim Otuya	KENET	Kenya	jotuya@kenet.or.ke
Moses Ojiambo	KENET	Kenya	mojiambo@kenet.or.ke
Zeinab Mzungu	KENET	Kenya	zmzungu@kenet.or.ke
Meoli Kashorda	KENET	Kenya	mkashorda@kenet.or.ke
Ronald Osure	KENET	Kenya	rosure@kenet.or.ke
Peter Muia	KENET	Kenya	pmuia@kenet.or.ke
Pascal Hoba	UbuntuNet Alliance	Malawi	ceo@ubuntunet.net
Tiwonge Banda	UbunutuNet CFO	Malawi	tiwonge.banda@ubuntunet.net
Traore Pierre Claver Bakoroba	MaliREN	Mali	pcbako.traore@usttb.edu.ml
Lourino Alberto Chemane	MoRENEt	Mozambique	lourino.chemane@mctestp.gov.mz ,lourino.chemane@morenet.ac.mz
Owen Osatahanmwen Iyoha	EKo-Konnect is a cluster of the Nigerian Research and Education Network (NgREN)	Nigeria	owen@eko-konnect.org.ng
Barry Boubakar	CEO WACREN	Senegal	boubakar.barry@wacren.net
Ahmed Dahir Siyad	CTO Somali REN	Somalia	ahmed.siyad@somaliren.org
Ibar Osman Ibrahim	SomaliREN	Somalia	ibarosman@somaliren.org
Abdullahi Bihi Hussein	Somali Research and Education Network SomaliREN	Somalia	abdillahibehi@somaliren.org
Kasandra Pillay	South African National Research Network SANReN	South Africa	kasandra@sanren.ac.za
Magreth Mushi	Tanzania REN	Tanzania	magreth.mushi@out.ac.tz
Regina Mboma	Tanzania REN	Tanzania	rmboma@ternet.or.tz
Alex Mwotil	Research & Education Network for Uganda, Makerere University	Uganda	mwotila@renu.ac.ug
Nicholas Mbonimpa	Research and Education Network for Uganda RENU	Uganda	cto@renu.ac.ug
Stein Mkandawire	Zambia REN	Zambia	mkandaws@zamren.zm

Stephen Simukanga	Chair UbuntuNet Alliace, University of Zambia	Zambia	stephensimukanga@ymail.com
Beatrice Ng'ambi	UbunutuNet		beatngambi@ubuntunet.net
Mike Last	WIOCC Network carrier (submarine, terrestrial, international)		mike.last@wiocc.net
Omo Oaiya	WACREN		Omo.Oaiya@wacren.net

Qualitative study description:
During the UbuntuNet Connect Conference (UC2018) in Zanzibar Tanzania, Dr. Heidi Morgan and Vasilka Chergarova conducted a case study research to explore different connectivity options with the UbuntuNet Alliance members. Below are the results of the study.

Methodology: The methodology used for the study is a qualitative interview-based survey (See Appendix A), open ended questions interviews and discussions, and observations at the conference events. The data was gathered in-between the conference sessions or via scheduled meeting time. Two of the representatives filled the survey online because they needed to consult with their technical staff in order to better answer the questions. The questions in the survey were created initially by the AARCLight PI and Co-PIs and later edited and refined in multiple rounds of discussions with the project partners. The questions were also translated to French for the French-speaking participants, however, most of the participants gave their answers in English.

Sample: The sample is comprised from 28 RENs representatives (e.g. ZAMREN, MoRENet, SomaliREN, etc.), from 14 African countries (Benin, Ethiopia, Jordan, Kenya, Malawi, Mali, Mozambique, Nigeria, Senegal, Somalia, South Africa, Tanzania, Uganda, Zambia), and the regional leaders in UbuntuNet Alliance and WACREN.

Research Questions: Exploring different options that are rational in terms of making the best use of the spectrum on SACS, WACS and MONET for this opportunity. We know fairly well the options for the submarine cables, but what about the connectivity of the NRENS to them?

Goal of the study: The goal of the study is to understand the interest of the African REN operators and the research institutions they support from a network connection in the South Atlantic for collaborative projects between the USA, South America, and Africa. This approach links into AARCLight Milestone 1: Establish AARCLight collaboration with UbuntuNet, WACREN, SANReN, TENET and other regional national research and education networks in addition to the U.S. and South American Partners.

Results: After a brief presentation of what the AARCLight project is about, Heidi Morgan discussed with the interviewed REN operators the current state of the infrastructure they support, the connected research institutions, and if they have collaborators in the USA and South America. The resulting documentation follows directly below.

Development of the RENs:
According to the CEO of the Tanzania REN (TANET), Magreth Mushi, the RENs first organize as a community and then later on evolve to actual connected network.

"Thank you we are 10 year, but anyway you see the way NRENs are starting in Africa is like very diverse. For us we started as a community of institutions and we did not connect members to physical connection until last year…last year October this is when we started connecting members. But before that it was a community of institutions, right. And we didn't provide…we provided service before that, we provided a mailing system, but now since last year we are doing connection, you know we are connected to the Alliance, we are connected via Nairobi, we are also connected to South Africa, and from there we go to GEANT."

The current African NRENs support varieties of educational institutions. With support of the government, TERNET initiated the connection of 27 of its 300 members, RENU (Uganda) supports 50 research institutions, SomaliREN has 40 members institutions (connected are 8 universities, one research center, a NOC, and others), and MoRENet has 133 institutions including higher education, research and Technical vocational schools (TVET).
Some RENs are still in a developing stage and do not have an infrastructure in place, but exist only as a community at this moment. In the case of MaliREN (Mali), which is one of the first members of WACREN, the universities and the research institutions are currently using commercial ISP providers for their Internet connection.

The bandwidth capacity of the African REN is also low due to the cost. For example, RENU (Uganda) has 3-5 Gbps, MoRENet (Mozambique) has 3-12 Gbps, SomaliREN (Somalia) has 155 Mbps. However, there is current tendency in lowering the bandwidth cost [21]. For example, Uganda Internet costs dropped by 73 Percent (US$70 per Mbps) in the last 3 years [22].

Services and connections:
TANET currently offers 13 services to its members (universities, colleges, and TVET). The model the organization is following is member-needs centered. Some of services are student's management information system, centrally hosted NOC, network connectivity, an email system, training and capacity building for member, Direct Engineering Assistance (DEA) for restructuring the internal institution network, collocation, private servers for hosting or backup, LAN and meeting management systems, and of development department that develop software for the connected institutions. MoRENet maintains the Mozambique HPC initiative, hosts an eLearning, content applications and services for the scientific academic communities. RENU has implemented eduroam, identity federation, Infrastructure-as-a-service, cloud and email services.

Challenges:
Current African REN operators have to compete with local ISP providers for cost of the network connectivity. Some of the commercial ISP are considering the RENs as a competitor and are purposely lowering the prices sometime under the market value to get more customers.

"And research …. you know main of the NRENs…. we have this challenge of having commercial providers person about the NRENs…. you know fighting for customers here and there"
CEO TANET

Some of the research institutions have adopted a hybrid model for network connectivity. For example, SomaliREN uses their network and leased capacity from a commercial ISP provider to supplement its bandwidth capacity. SomaliREN and MaliREN are looking at possibilities to lay their own fiber for their network infrastructure, but are challenged by prices of the fiber.

Another challenge is the lack of government regulations for the RENs in certain countries. There is expressed government support, but creating an actual telecommunication regulation takes time. However, there is a government support for the initiatives of the RENs. At the UbuntuNet Conference, two ministers of the local government were invited to open and close the conference. Their speech showed support for the NREN development and the research institutions involved. Government regulations and ISP connection providers, prices, funding, taxes, various political groups, recruiting, and ISP monopolies are the major challenges to the newly developed NRENs. Some of them are considering themselves as a startup. Also, there is a consortium of universities that got together and formed the REN.

Benefits to researchers from the USA, Brazil and Africa from the AARCLight project:
WACREN Team expressed significant interest in the opportunities to augment their network capacity by connecting to the new SACS cable system and to the exchange point in South Africa. They did not describe specific projects that would benefit directly from the exchange of information and experience but promised to provide this information in a later email communication.

UbuntuNet Alliance expressed the same enthusiastic interest in increasing the capacity for its members. Dr. Heidi Morgan met with the CEO of UbuntuNet, Pascal Hoba, and discussed the collaborative opportunity with him.

***Conclusions*:**
Network operators of newly developed African RENs expressed great interest in learning from more experienced network operators around the world that already operate research and education networks. A collaborative project like that can connect network engineers to exchange ideas, experience, and suggestions of how to make the best use of the cyberinfrastructure to support the collaborating universities.

"Connecting at layer 8 to produce an idea that can benefit both sides"
CEO SomaliREN

Future collaborative network engineering workshops between the USA, Brazil, and African nations can get us closer to achieving the goal of the Global Network Architecture to support the research and education.

Limitation of the study was that the instrument (the survey questionnaire) was developed for gathering qualitative data from the NREN operators and was not tested for internal and external validity. The questions were translated to French using and online translator, and then later validated by two independent (not certified) French speaking people. No participants answered in French, and no data needed back translation.

Future plans are to continue gathering data from the NREN operators, but also to create a similar questionnaire to gather data from universities' researchers and their collaborators at similar conference events. The results can be presented at the next UbuntuNet Conference in 2019.

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Appendix C: Submission to the UbuntuNet Connect Conference 2018

Following is the paper submission to the UbuntuNet Connect Conference 2018, Zanzibar, Tanzania.

AARClight - New opportunities for South Atlantic R&E Network collaboration between Africa, Brazil, and the US

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Abstract

Higher education and research science is being conducted in an era of information abundance. Sharing educational resources (e.g. Libraries, Curriculums, Online courses) and science resources, such as data commons, instrumentation, technology, and best practices, across national borders, can promote expanded global education goals and scientific inquiry and has the potential to advance discovery. Providing robust diverse Research and Education Networks (RENs) linking the U.S., Brazil (S. America) and African researcher and education communities is an increasingly strategic priority. Africa has developed research and education communities with unique biological, environmental, geological, anthropological, and cultural resources. Research challenges in atmospheric and geosciences, materials sciences, tropical diseases, biology, astronomy, and other disciplines will benefit by enhancing the technological and social connections between the research and education communities of these three continents via a S. Atlantic route to complement the existing North Atlantic routes via Europe.

This paper will discuss the availability of new submarine cable spectrum for RENs via SACS between Luanda, Angola and Fortaleza, Brazil and the Monet cable between Fortaleza and

Florida in the U.S. for use by research and education communities. This new infrastructure creates an unprecedented opportunity for the stakeholders to coordinate planning efforts to strategically make use of the offered spectrum towards serving the broadest communities of interest in research and education. The new links will be a foundational layer for the employment of R&E networks outfitted with leading edge technologies (e.g. Science DMZ, SDN, SDX, cybersecurity etc.).

The paper seeks to leverage a discussion of opportunities for a new R&E Exchange point at Luanda, Angola, other connectivity options, and to further promote discussion and identify synergies with UbuntuNet members.

Florida International University and AmLight consortium partners are planning, designing, and defining a strategy for high capacity connectivity research and education network connectivity between the US and Southwest Africa, called Americas Africa Research and eduCation Lightpaths (AARCLight). Furthermore, the other "end" of the SACS cable is being connected to an Open Fortaleza R&E Exchange point in Brazil. The new academic exchange point, South Atlantic Crossroads (SAX), is managed by Rede Nacional de Ensino e Pesquisa (RNP), where AmLight connects and continues on the Monet spectrum to Boca Raton Miami Florida. Having the transport service opened in Fortaleza will allow RENs from South America to collaborate with partners in Africa with significantly less delay, (at least 150ms lower) than using the current paths available. Interactive high-resolution video and big data applications will benefit from the establishment of the SAX international exchange point in Fortaleza.

Keywords: Research and Education Networks, Exchange point, US-Brazil-Africa Collaboration

1. Introduction

Linking South and North America via a South Atlantic high-performance Research & Education Network (REN) with the nations of Africa's researchers, students, knowledge creation and knowledge sharing communities has become an increasingly strategic priority[1]. Africa offers research and education communities with unique biological, environmental, geological, anthropological, and cultural resources. Research challenges in atmospheric and geosciences, materials sciences, tropical diseases, biology, astronomy, and other disciplines will benefit by enhancing the technological and social connections between the research and education communities of the US, Brazil, and Africa. For many years, we have seen the dramatic benefits of high-performance networking in all areas of science and engineering.

We present AARCLight (Americas Africa Research and eduCation Lightpaths) to provide a bridge from the current infrastructure, to one that will provide unprecedented resources for research and education communities.

2. New submarine cables in the South Atlantic

Several existing and new cable systems are interconnecting the continents in the South Atlantic as shown in Figure 1. The MONET cable which connects Boca Raton which further connect to Miami, Florida (USA) to Fortaleza (Brazil) is operational. The 6,165km South Atlantic Cable System (SACS) between Fortaleza (Brazil) to Sangano (Angola) was completed in Q3 2018 [2] and is operational. SACS is 100% owned and managed by Angola Cables who has entered into an agreement with Florida International University (FIU) for effectively 100 Gbps provisioned over spectrum using coherent WDM technology. SACS offer a total design capacity of 40 Tbit/s between Fortaleza (Brazil) and Luanda (Angola). Almost at the same time in September 2018 [3], the completion of the close to 6000km marine installation South Atlantic Inter Link (SAIL), Fortaleza (Brazil) to Kribi (Cameroon) was announced. The EllaLink system [4], Fortaleza (Brazil) to Sines (Portugal) is currently planned and aims to be Ready For Service (RFS) in 2020. The 17,500km America Movil (AMX-1) cable system, from Fortaleza (Brazil) to Jacksonville and Hollywood (USA) has been operational since 2015 [5]. AMX-1 has multiple landing points in Colombia, Brazil, the Dominican Republic, Puerto Rico, Guatemala, Mexico, and the United States. Seaborn's SABR cable system [6] is currently being developed to connect Cape Town (South Africa) to Recife (Brazil), and eventually the USA and will be RFS in 2029. Fortaleza (Brazil) is a landing point for all these cables, except for SABR.

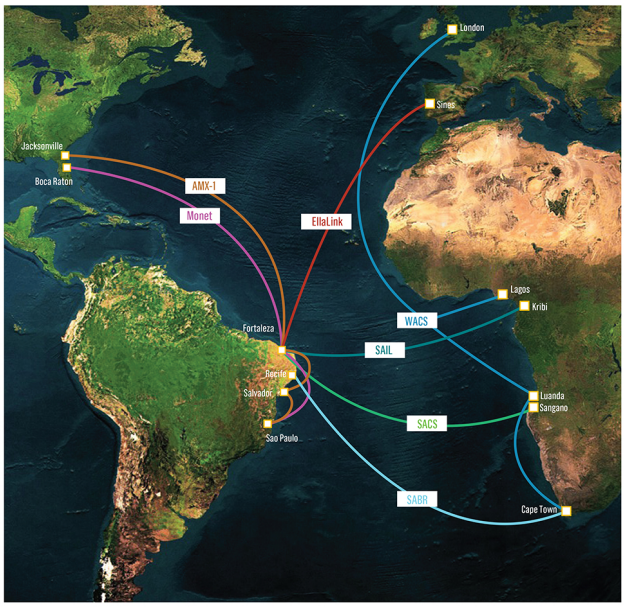


Figure 5 Submarine cables in the South Atlantic

3. Network performance to Latin America

In June of 2018 network performance tests (Table 1) from Cape Town to Latin America and the U.S. shows quantified improvement. The current latency data was provided by TENET over the UbuntuNet, GEANT and Internet2 links. The Estimated via SACS column shows improved performance using data collected from the Angola Cables IP network. The Possible Improvement column shows the percentage of the estimated improvement, ranging from 20% to 71% in reduced latency.

Table 3 Estimated performance improvement using SACS cable system

From Cape Town to:	Currently via TENET, UbuntuNet, GEANT, and I2 *	Estimated via SACS	Possible Improvement
New York	241ms	192ms	20%
Miami	272ms	161ms	41%
Fortaleza, Brazil	336ms	97ms	71%
Sao Paulo, Brazil	381ms	142ms	63%
Santiago, Chile	382ms	183ms	52%
La Serena, Chile	392ms	193ms	51%

* Data column 2 provided by TENET/Len Lotz June 2018, except NY. All else from Angola Cables

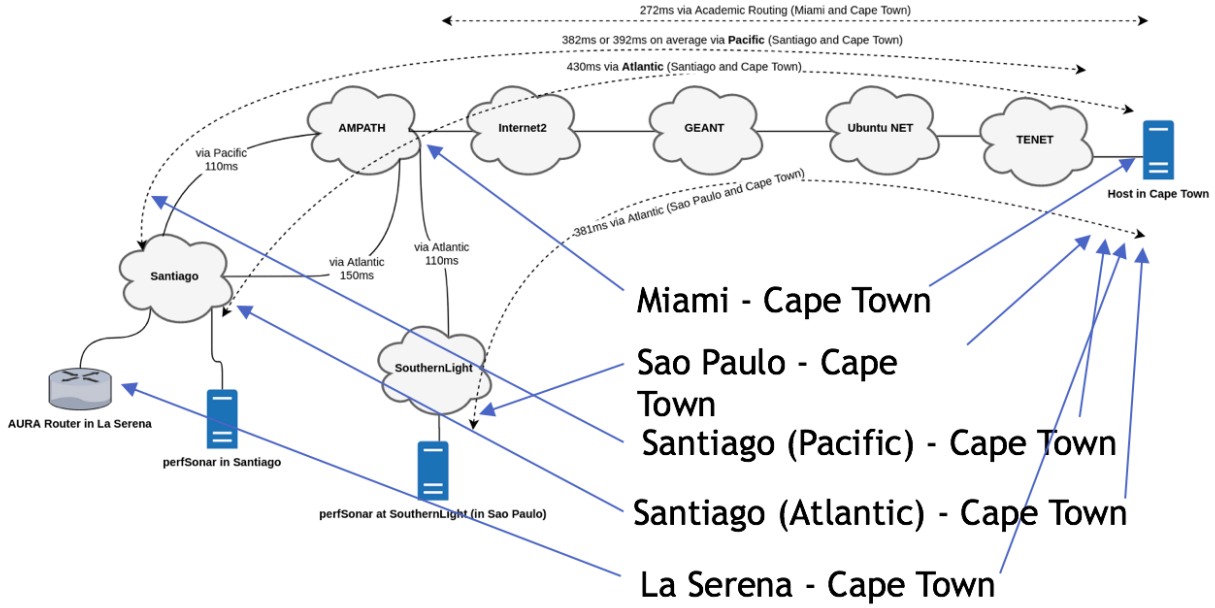


Figure 6 Conceptual network diagram of the tested network path

Figure 2 shows the conceptual network diagram of the domains involved in the tested path.

4. Americas Lightpaths Express and Protect (ExP)

AmLight ExP is a hybrid network that uses optical spectrum (Express) and leased capacity (Protect) to build a reliable leading-edge network infrastructure for research and education. It is connected at AMPATH and open exchange points in Brazil, Chile, Panama, etc. The total production bandwidth provided by AmLight ExP between the U.S. and South America will grow to more than 680G. Consortium members include FIU, Association of Universities for Research in Astronomy (AURA), Large Synoptic Survey Telescope (LSST), Rede Nacional De Ensino E Pesquisa (RNP), Academic Network of Sao Paulo (ANSP), Cooperación Latino Americana de Redes Avanzadas (RedCLARA), Red Universitaria Nacional (REUNA), Florida Lambda Rail (FLR), Telecom Italia Sparkle, Angola Cables and Internet2 (www.amlight.net).

Established in 2001, AMericas PATHway (AMPATH) is an Open R&E eXchange Point (RXP) in Miami - Florida, managed by the Center for Internet Augmented Research and Assessment

(CIARA) at FIU. AMPATH serves as the premiere interconnection point for U.S., Latin America, and Caribbean RENs. AMPATH works as a major research facility recognized by the U.S. National Science Foundation (NSF) and the US Department of Energy (DOE), and supporting international e-science.

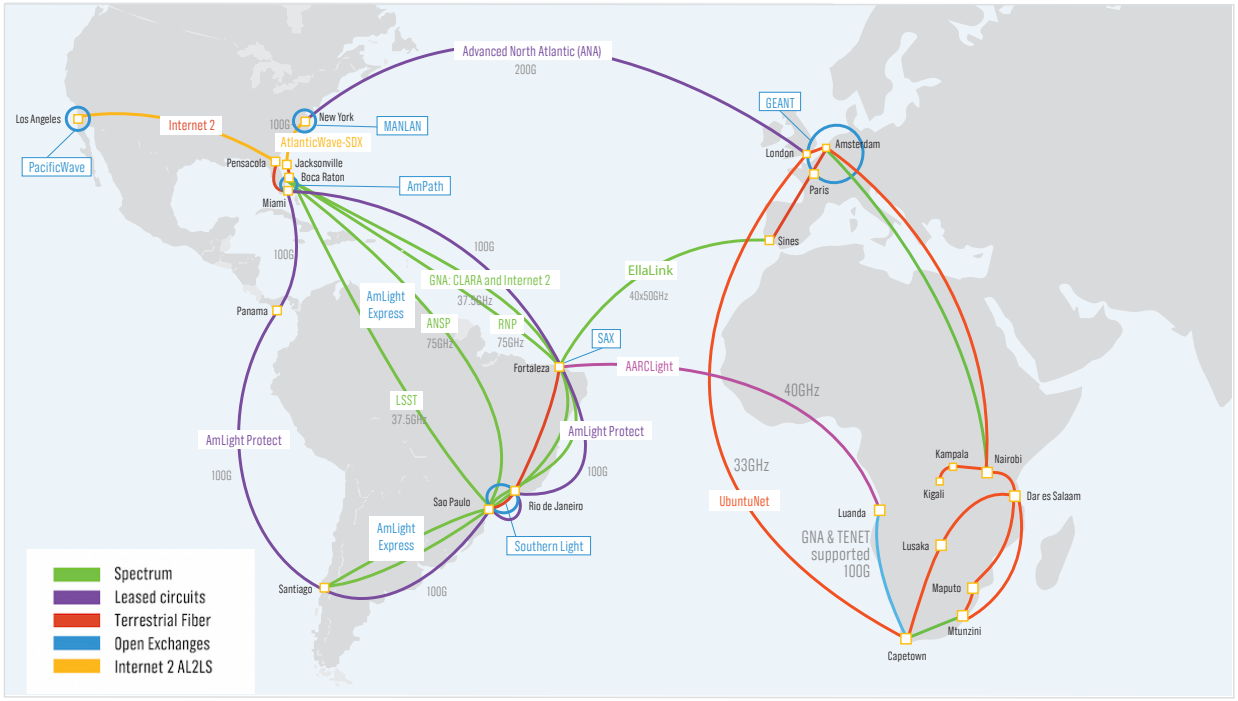


Figure 7 AmLight Conceptual Network Map

Currently, AmLight ExP operates an international network with multiple links connecting U.S. RENs to Central and Latin America: a 100G ring Miami-Fortaleza, Fortaleza-Sao Paulo, Sao Paulo-Santiago, Santiago-Panama City, and Panama City-Miami, a 10G ring from Miami-Sao Paulo-Miami for protection, and a 10G Miami-Santiago link for protection. The 100G and 10G rings are diverse, operating on multiple submarine cables. Total upstream capacity presently is at 230Gbps. AmLight network transports varieties of academic applications which requires reliable monitoring and troubleshooting tools. Figure 3 shows a conceptual network map of AmLight ExP and the network connections to South America, Africa, and Europe.

5. South African National Research & Educational Networks

The Tertiary Education and Research Network of South Africa (TENET) is South Africa's national research and education network organization. TENET operates the South African National Research Network (SANReN). SANReN and TENET jointly form South Africa's NREN (SA NREN) and operates an exchange point in Cape Town called ZAOXI. SA NREN has ownership of 7.4% of the WACS cable allowing it to light capacity between any 2 landing stations. AARCLight and AmLight are forming a collaborative partnership with SA NREN. The UbuntuNet Alliance can participate in this project through its connection in Cape Town. Additionally, UbuntuNet can participate by helping to establish an Exchange Point in Luanda. SA NREN can light capacity between ZAOXI and the new exchange point using WACS. Collaborative partners can utilize capacity as needed on the SACS cable, WACS cable, AARCLight etc. to connect to AmLight in Fortaleza, ZAOXI in Cape Town or any other connected Exchange point. SA NREN's WACS

connectivity may be extended to reach other landing stations to add new collaborative partners to the project.

6. Opportunity for new R&E Exchange point at Luanda, Angola

With two submarine systems (WACS and SACS) with landing stations in Angola (Figure. 4), an open exchange point in Luanda would act as a catalyst for revolutionary change in the Angolan research and education community. Currently, the universities all procure only commodity Internet connectivity. A task force has been organized to develop and build out an Angolan National Research and Education Network. Viable NRENs in West Africa are part of the focus of the European Union's AfricaConnect2 and AfricaConnect3 projects. As such, an open exchange point in Luanda could become a point of interconnection with WACREN. Furthermore, through both the 2010 MOU between Internet2 and UbuntuNet Alliance, as well as the UbuntuNet Alliance strategic plan, fostering interconnectivity between the U.S. research and education networking communities and those of UbuntuNet is considered to be mutually desirable.

The AARCLight project acts as a first direct physical infrastructure to support the long-standing

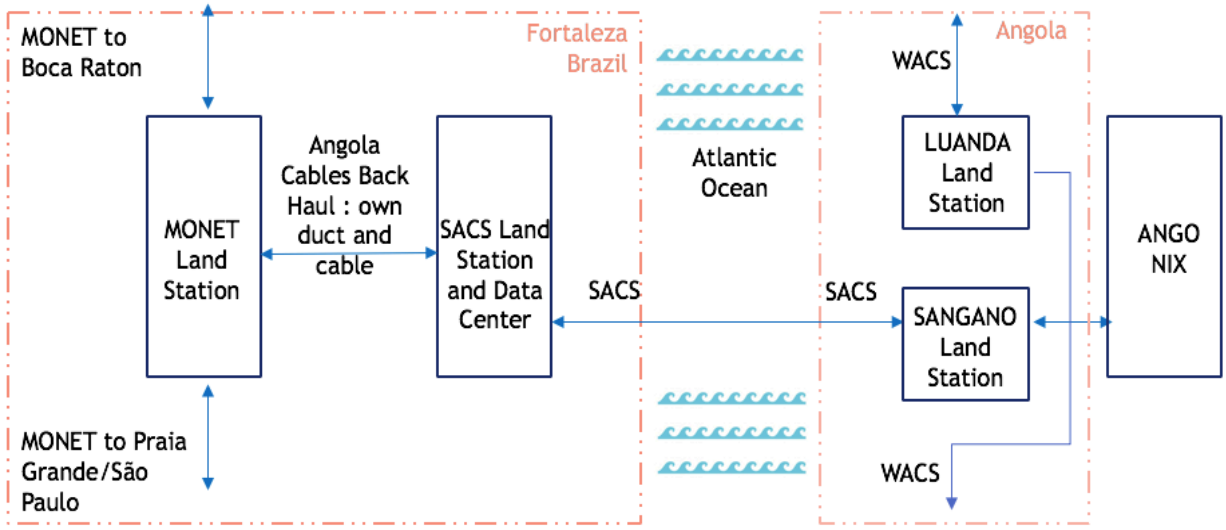


Figure 8 Logical diagram of landing station of SACS and WACS cable systems in Angola

desire for furthering Africa, Brazil, US network-enabled collaboration. AARCLight constitutes more than an incremental change in the infrastructure enabling collaboration. It is a technological tipping point that will enable the U.S., Brazil, Angola, WACREN, UbuntuNet Alliance, SaNREN, and TENET to exponentially increase the rate of collaboration, discovery, and learning.

7. New GOLE/GXP in Fortaleza: South Atlantic Crossroads (SAX)

The South Atlantic Crossroads (SAX) is a new academic exchange point, managed by RNP [7] in Fortaleza, Brazil. SAX connects to many Points of Presence (PoPs) within Brazil. In addition, RNP participates in the Global R&E Networks CEO Forum, and in particular in the planning of the Global Network Architecture (GNA) [8], which seeks to provide a rational global R&E network infrastructure. The GNA team has already identified Fortaleza as a critical point in the future design of this global network, due to its location at the narrowest part of the South Atlantic Ocean, thus providing an optimal location for exchanging traffic between Europe, Africa, and the Americas. Having the connectivity coming from Sao Paulo, Florida and Angola in Fortaleza allows R&E networks from South America to collaborate with partners in Africa with significantly less

delay, (at least 150ms lower) than using the current paths available. High resolution video and big data applications will benefit from the establishment of the SAX international exchange point in Fortaleza. An opportunity for using spectrum to reach continental US (via MONET), African R&E researchers could collaborate with partners in Brazil and the U.S., also with reduced delay, at least 100ms lower, compared to the current paths available.

Additionally, Fortaleza is a key aggregation point in the South Atlantic because of the multiple cable systems landing there. For example, the MONET cable, the SACS cable to Angola, and forecasted EllaLink cable to EU RFS 2020, and via RedCLARA to Los Angeles, CA, and future connections with other partners.

SAX is designed to be compliant with both GNA and Global Lambda Integrated Facility (GLIF) initiatives. GLIF is an international consortium that promotes the interconnection of lambdas around the world. GLIF International lambdas act as an integrated facility with the goal to support data-intensive scientific research. Since 2005, via conferences and workshops, it gathers the discussing equipment, requirements for connections, and essential engineering functions and services [9]. International partners, such as RedCLARA, AmLight ExP and GEANT, are crucial to providing the new circuits reaching SAX.

8. Americas Africa Research and eduCation Lightpaths (AARCLight)

Science is being conducted in an era of information abundance. Sharing science resources, such as data, instrumentation, technology, and best practices, across national borders, can promote expanded scientific inquiry and has the potential to advance discovery. Linking the U.S., Brazil, and the nations of Africa's research and education communities is an increasingly strategic priority. Africa offers research and education communities with unique biological, environmental, geological, anthropological, and cultural resources. Research challenges in atmospheric and geosciences, materials sciences, tropical diseases, biology, astronomy, and other disciplines will benefit by enhancing the technological and social connections between the research and education communities of Africa, Brazil and the US. FIU and AmLight consortium partners are planning, designing, and defining a strategy for high capacity research and education network connectivity between the US and West Africa, called Americas Africa Research and eduCation Lightpaths (AARCLight) [10] (NSF Award #1638990).

This planning project is largely based on the availability of submarine cable spectrum for use by research and education communities. It has created an unprecedented opportunity for the stakeholders in the U.S., S. Africa, and Brazil to coordinate planning efforts to strategically make use of the offered spectrum towards serving the broadest communities of interest in research and education.

9. Science Drivers

Multiple ongoing collaborative projects between the researchers from the U.S., Brazil and African communities can potentially benefit from the network connections in the South Atlantic. Here we are presenting only a few of the major projects involving astronomy, medical, agricultural and genomics research.

South African Astronomy applications: The South African Astronomical Observatory (SAAO) [11] is a facility of the National Research Foundation (NRF) [12], which operates optical telescopes, outreach and research located in Sutherland under the Department of Science and Technology. The Southern African Large Telescope (SALT) [13] is the largest single optical telescope in the southern hemisphere and among the largest in the world managed by SAAO. SALT is funded by a consortium of international partners from South Africa, the U.S., Germany, Poland, India, the

U.K., and New Zealand. Other SAAO Hosted Research Telescopes are BiSON [14], KELT-South [15], LCOGT [16], MONET [17], Solaris [18], SuperWASP-South [19].

The MeerKAT [20] 64-antenna array radio telescope located in the Karoo region is a precursor to the Square Kilometre Array (SKA) [21] and will be merged into the SKA1 (2020) with current data at a rate of 4.7 Gbps. SKA High frequency dishes will produce ten times the current global internet traffic and generate 960,000 Tb/day with rate ~160 Gb/s. SKA will be the largest array telescope in the southern hemisphere (2024) with collaborators from USA, Canada, India, Japan, China, Australia, France, UK, Italy, Finland, Germany. SKA Phase two will include telescopes from New Zealand, Botswana, Ghana, Kenya, Mauritius, Madagascar, Mozambique, Namibia and Zambia.

Brazilian Research and Educational Network (RNP) applications: RNP supports many science drivers complimentary to collaboration with African research interests. An agricultural collaborative research involving pest control on army worm (*lagarta do cartucho*) attacking maize and sorghum, is conducted between Brazil, U.S., South Africa, and nine other African countries and supported by Embrapa (Brazilian Corporation for Agricultural Research in the Ministry of Agriculture). Multiple ongoing collaborative medical projects with the African nations of the Community of Portuguese -Speaking Countries (CPLP) are established by the Brazilian Ministry of Health - Osvaldo Cruz Institute (FIOCRUZ) in collaborations with the National Institute of Infectology in Mozambique on clinical research and clinical tests. CPLP consists of the following countries: African countries: Angola, Cape Verde, Equatorial Guinea, Guinea-Bissau, Mozambique, and São Tomé and Príncipe. Non-African full members: Brazil, Portugal, and Timor-Leste. The scope of those projects includes infectious diseases as Malaria, STI, AIDS, Viral Hepatitis, and Tuberculosis. Another FIOCRUZ and Federal University of Rio de Janeiro (UFRJ) project in Angola is collaborating with the National Institute for Health Research (NIHR) of the Angolan Ministry of Health de Angola, currently investigating the genotyping and resistance of HIV-1 to anti-retroviral drugs.

The Atlantic International Research Centre (AIR-Centre) has agreements between the EU-BR-ZA for collaborative research activities in the South Atlantic and Southern Oceans
The ambition of the AIR Centre is to be a long-term platform for North-South, South-North, East-West and West-East collaboration in the Atlantic towards a holistic, integrative and systemic approach to knowledge on space, oceans, climate change impacts, energy and data sciences, while fostering an inclusive perspective to science, technology and economic development [22].

MoRENeT (Mozambique NREN has a long-standing collaboration with RNP participating annually in the RNP Forum since 2014. Activities include exchange of good practices in management and governance of research networks, IT training (including 25 techies in 2017 in Brazil), and exchange of information on technical and operational management.

Additional information about science drivers is gathered via the ongoing AARCLight project research survey. The 11th UbuntuNet Connect conference in Zanzibar, Tanzania created an opportunity to assess the e-cyberinfrastructure or the participating African NRENs and several responses from the CEOs, Senior Managers, and other African NREN representatives expressed a lot of enthusiasm in engaging in collaborative research between the U.S., Brazil, and the African communities using the increased capacity via the SACS network connection opportunity in the South Atlantic. Survey results will be published by year's end in the AARCLight Annual Report to the NSF.

10. Conclusion and suggested next steps

Based on multiple interactions with the stakeholders of AARCLight we have formulated five goals to guide continued collaboration toward full utilization of the new opportunities for South Atlantic

R&E Network collaboration between Africa, Brazil, and the US. The goals are as follows:

10.1 Investigation of an Open Exchange point in West Africa

We have begun systematically collecting data via a survey of potentail AARCLight partners to determine the strategic value to the R&E community to establish an open exchange point in Angola, or alternatively, to focus on extending an AARCLight link on the SACS cable to another location. Early results from the UnbuntuNet Connect Conference are being tabulated. At this time the collaborating partners are not at the stage to advocate the establishment of an Open Exchange point in Luanda, Angola. The nascent Angola NREN has not taken shape yet. The AARCLight team should continue to evaluate infrastructure enhancement. We have collectively agreed to employ exisiting infrastructure to effect connections on SACS, WACS, and AmLight-ExP between Africa and the Americas.

10.2 Develop a new network design in collaboration with AARCLight partners

AARCLight partners are engaged now, developing the equipment configuration to fully leverage the SACS and Monet submarine cable systems' spectrum allocation. The new network design shall respond to the following questions: How spectrum shall be used on the operational SACS cable? How to represent and describe interconnections to AARCLight partners in the U.S., Africa, Brazil, and the Americas? How to represent and describe connections to science projects and resources in Africa?

10.3 Develop additional goals and strategies to expand the scope of work based on findings from previous activities

Collaboratively develop an expanded project plan grounded on the findings and recommendations from AARCLight activities during 2017-18. Explore the feasibility of submitting a new five-year proposal to the NSF and other country partner funding agencies based on our findings.

10.4 Develop an assessment plan for the following objectives

First, assess the engagement level of the community of interest by conducting a formative and summative evaluation (see Survey Appendix A). Second, develop an assessment plan for the engagement level of the community of interest, the spectrum utilization, the shared vision and goals by the AARCLight partners, and the level of engagement with the potential new infrastructure.

10.5 Develop a plan for community engagement collaboratively with the stakeholders

Conferences, meetings, workshops and other relevant venues attended by representatives of the RENs and science application communities are important for AARCLight members to attend either in person or virtually. AARCLight PI, Co-PIs, and senior personnel shall continue attending relevant venues in Africa Brazil, and the U.S. attended by representatives of the RENs and science application communities. It is important to develop a plan for engaging communities of interest. For example, CANARIE (Canada's NREN) is a strategic partner for SKA (regional data center) and could be a strategic partner for AARCLight. The AARCLight team plans a future investigation for possible collaboration with the Canadian SKA Data center processing facility with regards to an alternative route via South Africa, Brazil, Florida, and Montreal (where the center will be located).

By diligently adhering to the above goals while concurrently moving forward to light the spectrum on SACS and make a connection to WACS the AARCLight project will successfully achieve a new beneficial international R&E network link in the South Atlantic for all stakeholders.

11. Acknowledgments

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