Extending High Bandwidth Academic and Research Networking to Africa

A Feasibility Study

Final Report

NSF Project SCI-0451384

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Executive Summary

This report is the final report of NSF Project SCI-0451384, *Extending High Bandwidth Academic and Research Networking to Africa*. The project was approved in September 2004 for one year and was extended for another year in late 2005.

The project has focused on the feasibility of extending the high bandwidth needed for real-time scientific collaboration and research networking to the African continent so that there could be effective collaboration between United States and African scientist, engineers, health professionals and educators. In addition to high-speed connectivity, the other major focus of the study involves providing support for the growth of an effective National Research and Education Network (NREN) to effectively use the newly provided high bandwidth.

Of all continents, Africa has been left behind in attaining high bandwidth connectivity to the global Internet infrastructure because of a vicious cycle of distance, slow economic development, high connectivity costs, universities lacking financial resources, and overall perceived lack of aggregate demand. The role of high-speed networking is vital for current scientific research, presenting Africa with a vicious cycle of lack of network bandwidth and lack of participation in international scientific research.

Two pilot countries were selected for the study, Senegal and Ghana. The selection was based upon accessibility to digital fiber cable, existing scientific research and collaboration with U.S. scientists, existing academic institutions, political stability, regulatory policy and the quality of the enabling environment for Internet growth. Several visits were made to both countries, and discussions were held with government, universities, the ISP sector, and the telecommunications operator in each country. Below market *pro forma* prices were negotiated for the intercontinental bandwidth — by far the most expensive part of any plan to extend high-speed bandwidth to Africa — with the operators.

In each country, we explored which institutions would provide an excellent venue for a national operations center to provide international and national Internet connectivity for NREN needs. In Senegal, Université Cheikh Anta Diop, the largest university in the country, was judged to be the best institution. In Ghana, the Kofi Annan Center in Accra was already involved in computational research in the sciences and is the location of an existing national Internet exchange point. Both locations could provide adequate security, climate control, conditioned electrical power, personnel and connection to the international backbone to support the NREN NOC, hereinafter referred to as the Information Exchange Point (IXC).

There is a substantial amount of scientific research ongoing between the countries selected and the U.S. Letters of support and need were collected from a variety of scientists and institutions on both sides of the ocean. Major partnerships can be achieved with GEANT for European and transoceanic bandwidth at no cost to NSF but

representing an in-kind contribution worth hundreds of thousands of dollars over the life of the project. Cisco is also interested in participating with in-kind contributions.

A project linking these countries with the global academic and research Internet obtains leverage from incipient NRENs in the countries. Both countries have a growing national fiber infrastructure that can be leveraged to support NRENs linking all major educational and research institutions in each country. The support and extension of such NRENs should be an integral part of any such project. Although we did not explicitly study the matter in detail, fiber exists in West Africa to connect other countries also, once the initial beachheads have been established.

This report contains a proposed implementation plan, including the allocation of duties among project leaders. Such a project could be proposed by NYSERNet, the New York State Education and Research Network, which has very substantial technical experience and a strong history in technical training.

In short, we find the project not only feasible but instrumental in meeting the current and future needs of U.S.-African scientific collaboration, as well as of general African Internet development.

Background

High-speed networking has been a driving force in science ever since the beginning of the Internet. In the 1980s in the U.S., NSF sponsored a series of five supercomputer centers and initiated a program of national networking to provide scientists with both computational capacity and the ability to access the network remotely using higher speed bandwidth than was previously available. This led quickly to advances in visualization that provided a quantum jump in scientists' ability to understand the results of their hypotheses and predictions. It is important to note that the availability of high bandwidth communications was a causal factor in increased scientific research capabilities and collaborations.

The situation has matured during the last 20 years, with access to very large databases, including access to research and other information on the World Wide Web being the major addition. High speed networks have also enabled the development of new collaboration tools that combine high resolution video conferencing, voice, white boarding and access to real time simulations (ACCESS GRID, VRVS). Dramatic increases in bandwidth in developed countries have rapidly stimulated increase in demand, and we should not anticipate any different expectations from collaborations with African scientists. Indeed, high bandwidth networks will make very large, and in some cases in Africa, unique databases available to scholars and educators on other continents.

Further advances in networking are actively being studied and deployed in developed country environments. Internet2 and its associated networks have been providing such connectivity for almost 10 years. Such “Next Generation Internet (NGI)” capabilities are also spreading to other parts of the world as well. GEANT is providing pan-European connectivity between NRENs; we also see NRENs developing in Eastern Europe, and in the Caucasus and Central Asia with the assistance of the NATO satellite-based Silk Road

project. Active work is now underway to explore both more effective and faster communication through optical wave networking and more effective access to computing power through grid technology. These technologies and others are regarded as important, enabling dedicated infrastructure services upon which much of current scientific research and education rests. If U.S.-African collaborations in science are to succeed, high bandwidth connectivity, as well as the new technologies that rest upon it, will be a necessity.

The "US-Africa Workshop: Enhancing Collaborative Research on the Environment in Sub-Saharan Africa," held in January 2005 at NSF, indicated increasing and significant collaborations between African and U.S. scientists, and the workshop represented only one specific related set of disciplines. Projects requiring high bandwidth included climatology modeling in Senegal, a cooperative project joining Howard University and Cheikh Anta Diop University (also known as the University of Dakar) in Dakar. While the workshop identified significant research collaborations that are evolving, "lack of adequate infrastructure in Sub-Saharan Africa (SSA), including IT capacity" was identified as one of the factors hindering strong and effective collaboration between U.S. and SSA researchers and negatively impacting the actual research questions being addressed.

The success of these and other collaborations increasingly depends upon high bandwidth connectivity that does not now exist. We believe that it is possible to make a dramatic change in that situation, starting initially with two countries. To the extent that such a change can be effected, collaborations in other, neighboring countries will be able to achieve the same connectivity with significantly less investment, leveraging from the international connectivity established through this project.

The National Science Foundation, through its International Research Network Connections (IRNC) program, has assisted countries outside of the United States to connect with the United States research and education community. Recent conferences supported and/or hosted by the NSF have pointed to a need to establish connectivity between U.S. researchers and their African counterparts.

The output of these conferences pointed to the fact that a significant amount of scientific research is being undertaken in Africa but that there is a dire need for African researchers, suffering under the isolation imposed by a lack of high-speed connectivity, to obtain assistance in establishing high-speed connectivity with the rest of the world.

In response to this need, the NSF has undertaken this project to ascertain the feasibility of providing such assistance, and if so, to show the best methodology for providing high speed connectivity to Africa in an effective, affordable and sustainable manner.

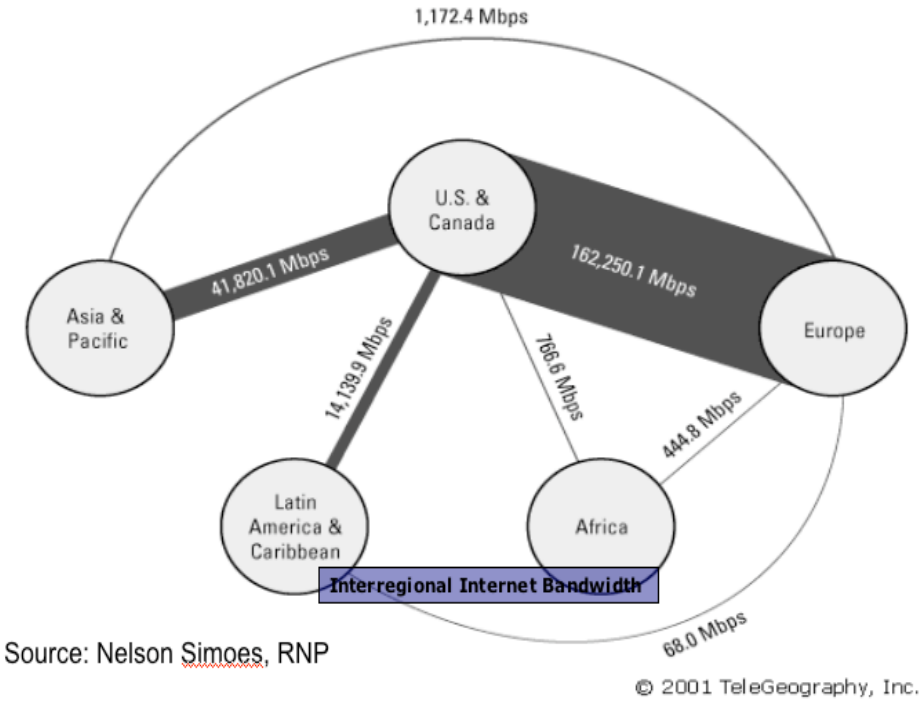
Specifically, this study will look at the feasibility of building high bandwidth Internet links to connect at least two African countries to the global Research and Education Internet for the purposes of assisting U.S. scientists to conduct research on African issues and with their African counterparts. The two initial countries chosen are Senegal and Ghana, because of their connection to the SAT3 submarine cable, their range of existing

cooperative projects already underway in which U.S. scientists and institutions are involved, and because the telecommunications and overall business policy situation provides an enabling environment for the establishment and sustainability of such links.

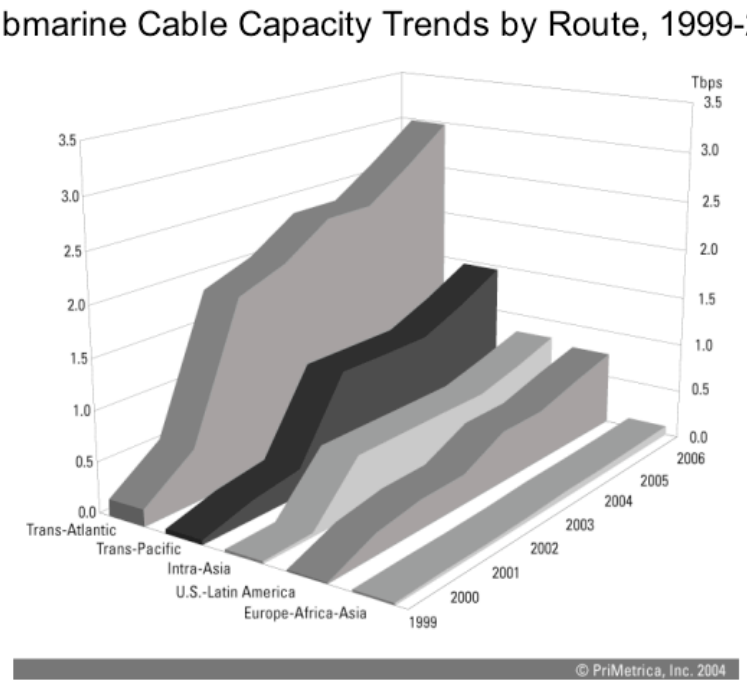
The primary goal of the project is to enable U.S. researchers and educators to have access to African resources and interact with African colleagues in research and education in science, engineering and medicine. High bandwidth links between these groups are as necessary between the U.S. and Africa as they are for the rest of the world.

Africa has long been the exception with respect to the ability of the Internet to penetrate and support a wide range of activities including business as well as research and education. Distance, absence of competitive international and national telecomm markets, and inadequate financial resources have combined to disadvantage the continent including the collaborative research that is already occurring, and that could take place in the presence of adequate bandwidth. Such bandwidth is considered essential to scientific research in developed countries. One cannot do much serious science in collaboration with developing countries that lack the bandwidth.

The following diagram illustrates the very substantial asymmetry that existed in intercontinental bandwidth several years ago:



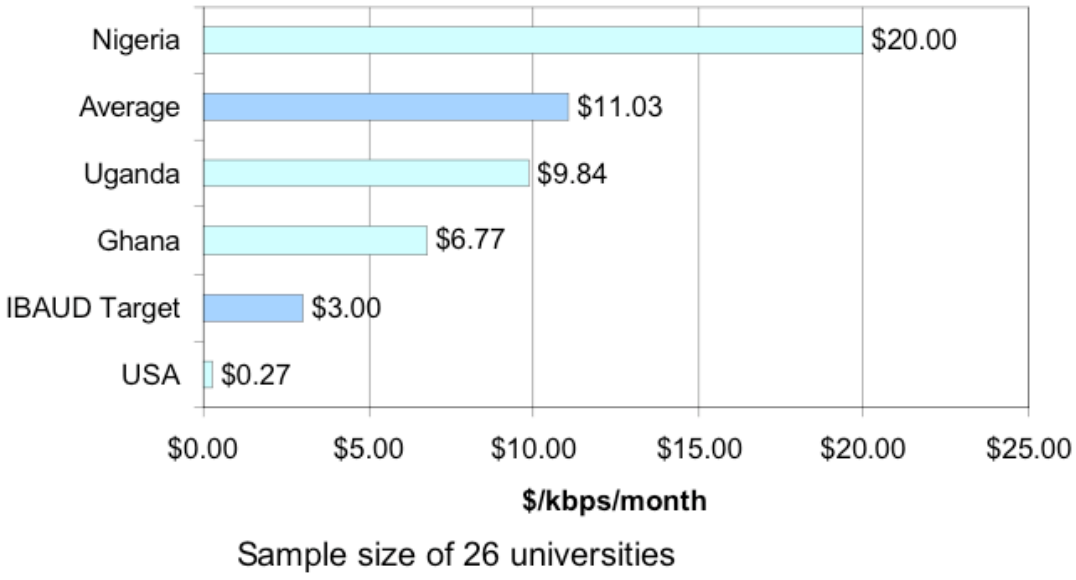
Furthermore, this trend does not appear to have changed. The graph below shows projected submarine cable capacity trends by route through 2006. Again, connectivity to Africa lags very substantially behind all other transcontinental routes:



International Bandwidth -TeleGeography research - © PriMetrica, Inc. 2004

Research and Education Networks in Africa

A number of recently completed studies have provided a reasonably up-to-date picture of research and educational networking in Africa. Funded by IDRC in Canada, the PAREN study (PAREN - Promoting African Research and Education Networking) provides one of the most complete pictures of existing regional national academic networks in Africa and in other developing regions. It concludes that, in Africa, Internet connectivity costs can be up to 100 times higher than those in developed countries. As a result, the total bandwidth access of the average African university is roughly equal to the bandwidth of a single home user (ADSL or cable) in North America or Europe.



In addition, in Africa there are very few formal NRENs that have developed. These conditions seriously impact the ability of African universities to conduct their missions of education, research, and exchange of information with their counterparts at the regional and global level. See:

- African Tertiary Institutions Connectivity Survey (ATICS) - http://www.atics.info
- Promoting African Education and Research Networking study sponsored by IDRC, by Roy Steiner and colleagues; January 2005: http://www.connectivityafrica.ca/page.php?Documents.html
- A Survey of investment in education and research networking in Africa; sponsored by IDRC; Kate Wild; June 2005: http://www.connectivityafrica.ca/page.php?Documents.html

Feasibility Study

Goals

The primary goal of the proposed project is to enable U.S. researchers and educators to have access to African resources and interact with African colleagues in research and education in science, engineering and medicine facilitated by high-speed Internet connections (local and international) and promotion of effective in-country National Research and Education Networks.

The secondary goal of the proposed project is to jump start intensive Internet penetration in these countries. Just as the appearance of high bandwidth networking in the R&E community in the U.S. caused an acceleration in commercial and personal networking, we anticipate that there will be a similar reaction, albeit more moderate, in the commercial and personal sectors in these countries. As college and university graduates become accustomed to increased network use in their professional lives, the demand for such capacity will grow outside universities and research institutions. ISPs already in existence in many countries have the knowledge and the ability to satisfy this demand, and can use the revenues from it to finance an expansion of their activities. Such expanding activities by many sectors will lead to sustainability of the project.

Pilot Country Selection

The first order of business was to select two pilot countries. All sub-Saharan African countries were examined for conditions that would permit an effective deployment of high bandwidth networking for the research and education community. The following criteria were used to narrow the selection:

Stable democratic government. It was considered essential to select countries with reliable and predictable governmental systems. Authoritarian governments may offer stability but are devoid of predictability. It was decided to restrict our choice to stable democratic regimes.

Liberal regulatory policy. The policies of telecommunications regulatory bodies determine what is possible and what is not possible with respect to new communications structures.

Higher education and research resources. The country had to have a number of institutions of higher education of substantial size, with a breadth of studies including training in sciences, engineering, and medicine, as well as other fields.

Collaborative scientific activities. Countries must have a number of collaborations between African researchers and U.S. researchers, with the possibility of additional collaboration if high bandwidth Internet connections were available

International fiber optic cable access. The country had to be connected to Europe or Asia via one or more submarine cables containing optical fibers. Satellite communication was not considered practical for high-speed bandwidth due to bandwidth limitations, asymmetry of transmitting and receiving speeds, high cost, lack of economies of scale and latency of response. Cable systems in the planning and early implementation stage were investigated and considered also, but will not affect the initial selections.

The criteria for evaluation of the countries can be classified into three major categories: (1) policies; (2) sustainability; and (3) possibility of scientific collaboration. After applying these criteria, Ghana and Senegal were chosen as the pilot countries. However, because Ghana and Senegal are on the SAT3 cable, they would have immediate access to collaborate with colleagues in South Africa, which is already on the Internet2 backbone and SAT3 cables. We would thus enjoy the benefit of collaboration with an African country with a well-established NREN to aid in our NREN activities in Ghana and Senegal while increasing the opportunities for research collaboration to include South African participation.

Study Methodology

To conduct the feasibility study, a team was constructed to include experts in the areas of African telecommunications and overall business policies, higher education networking, contacts with significant African and U.S. stakeholders, and public-private partnerships.

After the team was assembled, site visits to the two pilot countries were conducted to do on-the-ground assessments. Negotiations were undertaken to obtain pro forma pricing for bandwidth provision as well as space and support for the in-country Information Exchange Centers (IXC) – the focal point of in-country networking and NREN activities Using the information gathered through the above efforts, a complete project construction was undertaken to include:

- Network architecture (in-country and international)
- IXC location and support
- Stakeholders (including possible research collaborations)
- Possible Public-Private Partners (as evidenced by formal Letters of Support)
- Overall Project Management
- Project cost

Any project involving extensive use of ICTs needs to address three areas of concern:

- Policies (telecommunications and overall business climate)
- Infrastructure (existing, pertinent ICT infrastructures and new requirements)
- Stakeholders/Partners, including:
    - End- use stakeholders (end users that will use and benefit directly from the project: scientists, engineers, health care professionals, educators)
    - Enabling stakeholders (partners who are trying to benefit their target stakeholders via the project)

Our approach then, involved assembling a team of experts in these areas. Once assembled, the team made in-country visits to conduct evaluations and research on their areas of expertise. Additionally, the team undertook negotiations to obtain *pro forma* costs for bandwidth provision and housing and support for the Information Exchange Center — the in-country focal point for NREN operation and support.

Site visits to Ghana and Senegal included meetings with prospective stakeholders and potential partners. These stakeholders included government and university officials since both are key stakeholders in the project's activities.

The team also contacted potential U.S. partners/stakeholders to ascertain their support for the proposed project, and received letters of support for the project. While all the letters are important, one offer of support from the European high-speed network GEANT to provide our network free transport across Europe and onward to the Internet2 network in the U.S., if monetized, would be valued at hundreds of thousands of dollars. Another promising ongoing interaction with Cisco is likely to yield a significant contribution also.

Policies

Experience has taught that no matter how well thought out a project may be, if the national policies that impact the project are a negative influence, achieving success can be very difficult. We thus engaged the policymakers in both Ghana and Senegal to determine the impact of their pertinent policies on the proposed project. Of specific importance - would wireless spectrum be available for the project. This is required since, due to a lack of physical infrastructure in some areas, a wireless approach would need to be considered for last/first mile connections. While in the U.S. WiFi frequencies exist in the unlicensed band and can be utilized easily by virtually anyone, in Senegal for example, all frequencies are licensed and the Regulator must approve their use. Fortunately, in both Ghana and Senegal, the authorities assured us that spectrum would be made available for this proposed project since it benefited the educational sector.

Infrastructure

International connectivity between the U.S. and Africa is very small in terms of overall bandwidth (see Figure 1). This is a result of Africa having only one submarine cable provider for most West African countries (Atlantis 2 connects only from Dakar to Europe and South America) and a few, expensive satellite providers. This has lead to several efforts to assemble bandwidth-purchasing consortia to bargain for lower prices via economies of scale. The most notable effort here has been undertaken by the Partnership for Higher Education in Africa, which has successfully negotiated reduced bandwidth prices, via satellite, for the activities of the African Virtual University.

For technical reasons, satellites do not lend themselves well to high speed, real-time collaboration activities. Since such collaborations are a critical success factor for this proposed project, our only existing solution would be to construct our international network utilizing the monopoly submarine cable provider SAT3. Again, we were very fortunate in that we were able to negotiate informally very favorable/reduced pricing with Sonatel and Ghana Telecommunications (GT), the SAT3 representatives for their respective countries. Both Sonatel and GT recognized the importance of this proposed project to their educational communities and are considered as contributing partners due to their offer of significant price reductions. The cost of the international portion of the network is also significantly reduced by the offer of GEANT, the European high-speed research network, to provide the proposed project with free transport across Europe and onward to the Intenet2 network in the U.S. If this donation were monetized, it would be worth hundreds of thousands of dollars over a 5-year project life.

The international network would be constructed in two phases. Stage 1 would result in connectivity at the 45 megabits level from/to Dakar, Senegal and Sessimbra, Portugal. In Sessimbra, the network would be backhauled to Lisbon where it would enter the GEANT network for onward transport throughout Europe and onward to the U.S. The second phase would be the addition of a connection between Accra, Ghana and Dakar resulting in providing a 45-megabit connection to the research community in Ghana.

In country, we would need to get from the cable landing to the Information Exchange Center (IXC) in order to further distribute the bandwidth to the end-users. This backhaul would be accomplished via fiber cable or wireless modems depending on technical and cost considerations. In Senegal, the IXC would be located on the campus of the national university and would be distributed throughout the campus using the existing fiber backbone as well as Wifi/WiMax solutions. WiFi/WiMax would be the technology of choice for reaching stakeholders at a distance from the university campus. The University of Dakar would be the primary educational institution involved in the research and education consortium. Its 1,000 faculty members and its 42,000 students, including graduate programs, would play a strong part. In addition, there are two other major universities that are far from the University of Dakar campus, Thies and St. Louis Universities, however both could be reached via existing terrestrial fiber from the IXC.

In Ghana, we believe that the most viable lead institution is the Ghana-India Kofi Annan Centre of Excellence in ICT in Accra. Established by the government in 2003, it includes an Advanced Information Technology Institute with a Param Padma supercomputer, and

a mission of supporting, among other things, scientific research. We believe that the IXC would be best supported at this location. A Ghana Internet exchange point has recently been installed in this location, so that in addition it will be at the center of connectivity for the country. A letter of support from the Minister of telecommunications, who heads the Centre, has been obtained.

Allied closely with the Kofi Annan Centre would be the University of Ghana at Legon, the premier institution of higher education in the country. The university would be a major player in the research and education consortium that would be set up to distribute the bandwidth to other qualifying institutions in the country. It should be noted that the University of Ghana is one of the institutions receiving funding from the Partnership for Higher Education in Africa and we have been discussing ways to collaborate in Ghana with the Partnership. On the campus at Legon is the Noguchi Centre, which is a premiere research institution for malaria and other tropical diseases and which has been the recipient of significant funding from NIH. In addition, there are the 13 laboratories of the Centre for Industrial and Scientific Research (CISR). We would be able to connect those labs located in greater Accra via a wireless solution, but the labs distributed elsewhere in the country will need to connect via the soon-to-be constructed VSAT network.

Stakeholders

In addition to those universities and research facilities discussed in the previous section, there are numerous other stakeholders as evidenced by the following Letters of Support:

Projects With Ongoing Research/Activities in Ghana and/or Senegal

Prof. Sekazi Mtingwa, African Laser Centre, Harvard University (offer of ongoing research collaboration with the African Laser Centre locations in Ghana and Senegal. **Note: This Centre is one of the activities singled out for proposed monetary support of some $20 million by the New Partnership for African Development's 2006-2010 Science and Technology Action Plan)**

Dr. Gregory S. Jenkins, Director, Howard University Program in Atmospheric Sciences (has an ongoing research project in regional climate modeling in collaboration with the national university In Dakar that has been severely hampered due to low bandwidth. He thus supports the project, as it will provide immediate research benefits)

Prof. E.H.K. Akaho, Director General, Ghana Atomic Energy Commission (offer to host IXC plus ongoing research collaboration possibilities in several areas including Biotechnology, Mathematical and Computing Sciences and Nuclear Data development and analysis with their onsite research nuclear reactor)

Richard P. Dick, School of Natural Resources., Ohio State University (supports project as important to his NSF-funded program in Senegal on Geoscience/Biocomplexity)

Drs. James Woolliscroft and Timothy Johnson, Univ. of Michigan Medical School (support for the program and importance to their ongoing collaboration with Ghana University in the area of medicine)

Albert Kan-Dapaah, Minister of Communications, Republic of Ghana (assurance of policy support as well as hosting of the Information Exchange Center (IXC) at the Kofi Annan Technology Center which he directs)

Dr. Abdou Salam Sall, University Cheikh Anta Diop of Dakar (UCAD) (promise of academic cooperation, ongoing research collaborations In atmospheric science and African Laser Centre plus hosting of the Information Exchange Center {IXC} on his campus)

Mora McClean, CEO, The Africa-America Institute, New York, NY (support for project and Its Importance to their program to connect with some 22,000 African alumni from their many years of educational programs)

Dr. Emmit Bud Evans, California Polytechnic State University (starting a project with Ghana to create a Consortium for Academic Exchange Through Global Communications Technology which would be greatly assisted by the existence of high speed Internet)

Offers of Strong Support and/or Future Collaborations in Africa

Hamadoun I. Touré, Director, Telecommunication Development Bureau and Director-General elect, ITU (highest level support from the head of the foremost worldwide UN agency for telecommunications)

Prof. J. Anamuah-Mensah, Vice Chancellor, University of Education, Ghana (research support plus IXC hosting offer)

Dr. Phillip L. Clay, Chancellor, Massachusetts Institute of Technology (offer of research collaborations with MIT)

Thomas Nygren, Executive Director, Aluka Project, Ithaka Harbors, Inc.,Princeton, NJ (offer of collaboration with their online library, with search and analysis tools, on African-focused areas of research)

Tom Defanti, Professor, University of Illinois at Chicago; PI, NSF IRNC Grant: TransLight-SL (offer of network technical support as well as overall support for the providing high bandwidth to Africa for research)

Joe Mambretti, Director, International Center for Advanced Internet Research, Northwestern University (an NSF Partner in the International Research Connection program offers his support for the project)

Parvati Dev, Stanford University School of Medicine (support for high bandwidth project as critical success factor to their ongoing technology-supported learning efforts in Africa)

Solomon Bililing, Dept. of Physics, North Carolina Agricultural and Technical State University (support for, and offer of future collaborations with, the project in the areas of theoretical physics, seismology and geosciences)

Jeanne Altmann, Princeton University (support for project and for future collaborations with research in behavioral ecology and primate biology ongoing in Kenya)

Dr. Estella Atekwana, Department of Geological Sciences & Engineering, University of Missouri-Rolla (support for project and its future importance to their NSF-funded projects in southern Africa)

Hoffman Moka Lantum, MD, PhD, President, African Society for Toxicological Sciences (support for the project and Importance of high bandwidth to their programs dealing with toxicologists and environmental scientists)

Prof. Gilbert L. Rochon, Purdue University (with several Purdue colleagues he offers research collaboration on Remote Sensing of Environment, Photogrammetry, Geomatics and Infectious Disease Vector Mapping)

Nithaya Chetty, School of Physics, University of KwaZulu-Natal, Pietermaritzburg, South Africa (attestation of importance of high bandwidth their research and offer of collaboration)

Simon H Connell, Physics Department, University of the Witwatersrand, Johannesburg, South Africa (attestation of importance of high bandwidth their research and offer of collaboration)

Dr. Ron Hutchins, Associate Vice Provost for Research and Technology and Chief Technology Officer, Georgia Institute of Technology, Atlanta, Georgia (support for the project and its equal Importance with connecting other regions of the globe)

Prof. Fredrick H. M. Semazzi, North Carolina State Univ., co-chair of January NSF workshop "Enhancing Collaborative Research on the Environment in Sub-Saharan Africa" (offers support for the project and discusses its critical importance to the African science community)

Public-Private Partners

Several partners are interested in assisting us with this work. Sonatel and Ghana Telecom have agreed to pricing significantly below published retail rates, including fiber available to connect from the cable head end to the IXC.

On the Global Internet R&E side, we have offers of support and assistance from U.S. IRNC PI's for the TransLight/SL and TransLight/PW projects, Internet2, and the Internet2 NOC at Indiana University. On the European side, we have offers of

connectivity support through Europe with onward connection to the United States from the E.U. research network GEANT.

Potential partners in the field are numerous, and reflect the increasing focus upon the importance of extending modern digital communications into Africa in a meaningful way. We have had a variety of discussions with a number of these organizations, in part during the African Networking workshop held in early May 2005 as part of the Internet2 Annual Meeting. We agreed to keep each other informed about our activities and look for opportunities for meshing our efforts together as plans and activities evolve over time. Upon actual funding of this proposed project, these discussions of possible collaboration could then move forward as an extension to this project in a more meaningful way. The list of potential partners, with projects currently underway or planned in Africa, include USAID, NIH/NIAID, the World Bank, Partnership for Higher Education participating foundations, IDRC, GVU/NORAID, AFUNET and the Association of African Universities (AAU-Accra) which has recently taken a leadership role in the establishment and functioning of African NRENs.

Intellectual Merit

Implementing such a project would provide, for the first time (with the exception of South Africa), a high-speed submarine cable link to specific countries in Sub-Saharan Africa dedicated to supporting the research and education community. The link and the Information Exchange Centers would provide the foundation for providing a state-of-the-art high performance layer 3 exchange and peering fabric for the African R&E community. This activity would act as a catalyst to spur development of terrestrial fiber-based infrastructure connecting universities within countries and also between countries. Access to a high capacity link would act as a magnet to draw other links to the exchange points, and provide the stimulus and base for developing national R&E networks (NRENs) within each country.

The primary impact would be as an enabler for improved collaboration between U.S. and African researchers. Many collaborations already exist and are evolving. But the quality and scope of the collaboration have been seriously constrained by international bandwidth limitations. As evidenced by the letters of support obtained, the proposed link and resulting infrastructure improvements are expected to have a significant impact on the quality and breadth of research collaborations. These collaborations include environmental and earth science, ecology, astronomy, biology, distance education, medicine, engineering and materials, and physics. Applications and capabilities that would be enabled include data and image archiving, development and deployment of a computational grid, visualization, dedicated sensor deployment, remote instrument access and control, and digital libraries. The research activities ongoing in Senegal, Ghana and South Africa are numerous and of interest to U.S. researchers.

The broader impacts of this project are likely to be a revolutionary change in the speed and degree of penetration, not only of NRENs, but also commercial and personal Internet services in the countries served. We anticipate that the introduction of broadband Internet services for research and education would create a heightened sense of awareness of the uses to which such bandwidth can be put, and this will increase commercial and individual appetites for such services in the rest of the country. Among other things,

there could be joint projects between the education sector and others in the community that would serve to demonstrate the utility of bandwidth more adequate for a range of services not possible using the relatively meager bandwidth that exists today.

The prevalent method of obtaining broadband of sorts in developing countries has been through satellite technology, generally VSAT technology. Satellite technology not only does not scale affordably to multi-megabit or higher speeds in a way that provides economies of scale, but also requires one additional 50,000-mile hop, which degrades real time communication.

In particular, universities in general have had a tendency to spawn technical incubators, both in developed and developing countries. Strengthening universities' networking capabilities would make technological entrepreneurship more feasible, and would provide an increment of economic growth for the countries. Fiber is the scalable medium for bringing meaningful bandwidth not only to the research and education community, but also to users in general. Provisioning the universities and related organizations with broadband access would provide a powerful demonstration of that fact. In addition, the IXC and related strategies for sustainability would provide key foundational elements of this project.

It is worth recalling that the development of the Internet in the U.S. started in the research and education sector, and its use and visibility there seeded and fueled the growth of the commercial Internet. Parallel experiences in other countries are common; the education sector is prominent in starting the activity, which then spreads within the country. The analogy between the U.S. and an African country is certainly not perfect, but the effects, different in scale, are likely to be the same. The NREN investments in countries in Eastern Europe, and even in Central Asia to a lesser extent, support this model of development.

Aiding in this diffusion into the commercial and personal sectors will be the stepped-up plans for targeted assistance to Africa that are evidenced in the recent U.K report for aid to Africa, the World Bank's increased interest in assistance to Africa, and the forthcoming G-8 focus upon increased aid to Africa. Additionally, the New Partnership for African Development (NEPAD) has proposed millions of dollars of assistance in its 2006-2010 Science and Technology Action Plan. Such assistance will surely include assistance to the business sector and its integration into the world economy through increased international trade and affiliation with the WTO. These international linkages will be facilitated by adequate and reliable connectivity with partners in other countries and continents.

Furthermore, as African universities evolve in their sophistication of using, and more pervasive access to, modern computing and its technologies, it will impact both the capacity for research and the quality of research performed. It will also impact the nature of the workforce educated by those institutions – acting as a technology transfer mechanism and economic development stimulus. This transition will also greatly help to ameliorate the digital divide separating African scientists from the rest of the world.

While the primary purpose of this project will be to support cooperative U.S.–African research and education, these broader impacts may achieve a scale that will produce a communications revolution in the countries that are involved.

Project Realization and Management

Strategic Plan

In developing a project plan for improving connectivity to African universities and researchers, it was recognized early on that such a project would be quite different in nature than the IRNC proposals, which NSF funded during previous years. Those proposals were developed with strong partners on the other side (Europe, for example), with experience and a history in some level of high performance networking. Due to the cited lack of international connectivity and infrastructure, any effort in sub-Saharan Africa must deal with the reality of a lack of infrastructure on the ground in each country, and no strong partners (within the advanced networking context) with whom to collaborate. Any such effort must cope with the difficult environment of developing countries with monopolistic telecom histories and tendencies that have limited access and capabilities, that have kept prices artificially high.

Thus the proposed project has been defined to take this into account. It has short-term strategies and action plans based upon a level of NSF funding, state of development on the ground, and realistic expectations for obtaining bandwidth within the project budgetary boundaries. It also has longer-term strategies that can be successful through encouraging private sector relationships, and building relationships and collaborations with other similar infrastructure projects and well defined African research initiatives.

The short term plan involves free access to GEANT in Lisbon (and thus the global research and education network, including Internet2), terrestrial backhaul between Lisbon and Sisembra on the coast, and below-market negotiated pricing for submarine cable capacity over the SAT-3 cable to Senegal and Ghana.

On the ground in each country, terrestrial fiber or wireless technology would connect from the cable head end to the partner institution, the "National Coordinator," and the "Information Exchange Center" (IXC) that would be established there. For both of the countries proposed for the first stage of this project, we have been able to obtain agreements for accessing this fiber connection. Within the country, we would work with the National Coordinator institution, the government and other partners to develop an NREN with connections to other universities and research institutions – in a "hub and spoke" model.

Our initial connectivity would be planned to be at 45 mbps bandwidth, based upon currently negotiated pricing – while much below commercial rates for these countries, it is still high. However, we anticipate that as such a project would proceed, we would be able to take advantage of closer relationships with the telecomm carriers, technical progress, and falling prices in order to increase bandwidth through the life of the project.

NREN Research and Education Network consortia

A central element in our proposed project is laying the groundwork for establishment of a national research and educational networking (NREN) consortium in each country. We would recommend to partner with those NREN efforts already underway, e.g., in Senegal, IDRC (Canada) is already funding an NREN study and the African Virtual

University office in Accra sponsored an AAU conference on NRENs in West Africa in anticipation of funding to begin establishing such networks.

A primary responsibility of each NREN consortium would be to provide a governance structure and coordination mechanism for developing the internal networking in the country to connect all significant research and educational institutions to the international gateway, and to manage it in an efficient and equitable manner. Consortia would also be encouraged to build a shared technical competence, as well as a leadership position in training in the use of informatics for educational and research purposes.

This model parallels the development of the Internet in the United States, where the NSF provided the initial national Internet backbone, and encouraged regional groups of universities to establish regional networks to connect to it. This model is also being promoted and employed in other developing countries. For example, in the Newly Independent States (Caucasus and Central Asia) under the NATO funded Silk Road project, nine countries have NRENs in development. While not complete, TERENA has begun an effort to try to catalog the various NREN efforts around the world, with financial support from the Information Society Technologies Program of the Commission of the European Communities. The TERENA NREN Compendium (http://www.terena.nl/compendium/) currently contains information on fifty (50) NRENS around the world, including three in Northern Africa.

Establishing the Intercontinental link

Today in Africa, there are only a very few existing cable systems that serve the West Coast of Africa. The two most notable are the SAT-3/WASC submarine cable system, which lands in 9 countries on the continent of Africa, and Atlantis 2, which lands in Senegal from South America. The SAT-3/WASC cable system is connected to the SAFE cable system in South Africa, which terminates in Malaysia via drop offs to Réunion, Mauritius and India. Consortia of international operators own both of these latter two cable systems. Internationally licensed operators who are not part of the consortia can purchase capacity on the SAT-3/WASC/SAFE cable system in the form of an IRU (Indefeasible Right of Use). Other submarine cable systems are being planned, but will not be available for some time, for example, the Eastern Africa Submarine System (EASSy), the Infinity West Africa (IWA) network and the Madagascar International Cable. We are also seeing capacity upgrades on (SAT-3/WASC via DWDM) being effected to meet anticipated increases in demand.

Participation in the next anticipated upgrade of the SAT-3/WASC/SAFE cable system (ultimately 120 Gb/s system capacity on SAT-3/WASC portion) is limited to current owners in the cable system. Details pertaining to the upgrade equipage and related costs cannot be provided to non-owners. We have engaged in discussions with four different owners of capacity in SAT-3 (South African Second National Operator equity owner, Telkom South Africa, Sonatel and Ghana Telecom) to realize donations and/or acquisition of capacity at some combination of incremental costs and O&M responsibility.

The immediately available solution, as determined at our meetings with Sonatel and Ghana Telecom, is to obtain capacity in the cable system by leasing it from them at negotiated, below market rates. Based upon both the current capacity and technical

configuration of the SAT-3/WASC cable, plus budget limitations, the proposed plan would be to initially lease capacity at the 45Mbps level between Africa and Lisbon, Portugal. As usage of the capacity increases, as prices continue to fall, and the anticipated cable system upgrade occurs, we anticipate the possibility of upgrading the capacity from 45 Mbps. to 155 Mbps.

The discussion with both landing parties in Ghana and Senegal is centered on the provisioning and delivery of a 45Mbps at each of the cable stations in Accra, Ghana and Dakar, Senegal for the proposed NSF project. We continue to correspond with Sonatel in Senegal and Ghana Telecom in Ghana on incremental cost options on the cable system in which both operators are planning capacity upgrades. We have had ongoing conversations and correspondence on technical and administrative plans and practices with the Cable Administrator for SAT-3/WASC, Telkom South Africa. Both Ghana Telecom and Sonatel have been receptive to incremental based cost model as a means to deliver international bandwidth to the Research and Education community in their country.

The proposed locations for the Information Exchange Centers (IXCs) where the bandwidth would be delivered and distributed are less than 10 kilometres from the cable landing station in each of the countries. We have confirmed the availability of dark fiber from each of the incumbents at their cable stations so that we have a choice of a fiber or wireless connection to the respective IXCs. In the initial application, the handoff proposed would be a gigabit Ethernet interface at the IXC using rate limiting to match the international capacity.

It is expected that the IXCs may well emerge as regional exchange points and begin to expand the connectivity footprint beyond the local and country borders. There is fiber infrastructure available to nearby countries as well as interest to utilize this fiber infrastructure to interconnect additional locations. The National Coordinator would manage such cross-connects.

The Information Exchange Center (IXC)

The proposed IXC is a facility designed to support scalable growth for service and application providers along with the research and development not-for-profit community in a geographic region that allows network connectivity in a neutral open environment. The IXC would be positioned to support the establishment of a regional and international exchange point with the suitable physical infrastructure. It would be provided with sufficient air conditioning, public power, UPS equipment and backup electrical generating equipment to provide a level of reliability for the network well in excess of what has existed in these locations to date. It would initially house the POP and the NOC for the link, but would have sufficient physical capacity that it could also serve web hosting and other specialized needs that service the research and education community in science, engineering, and health. The IXC would be located in a separate secured building or building extension constructed to allow for expansion as needed. For example, it would have the capacity to support a “telemedical science” exchange point as medical networks expand the network topology.

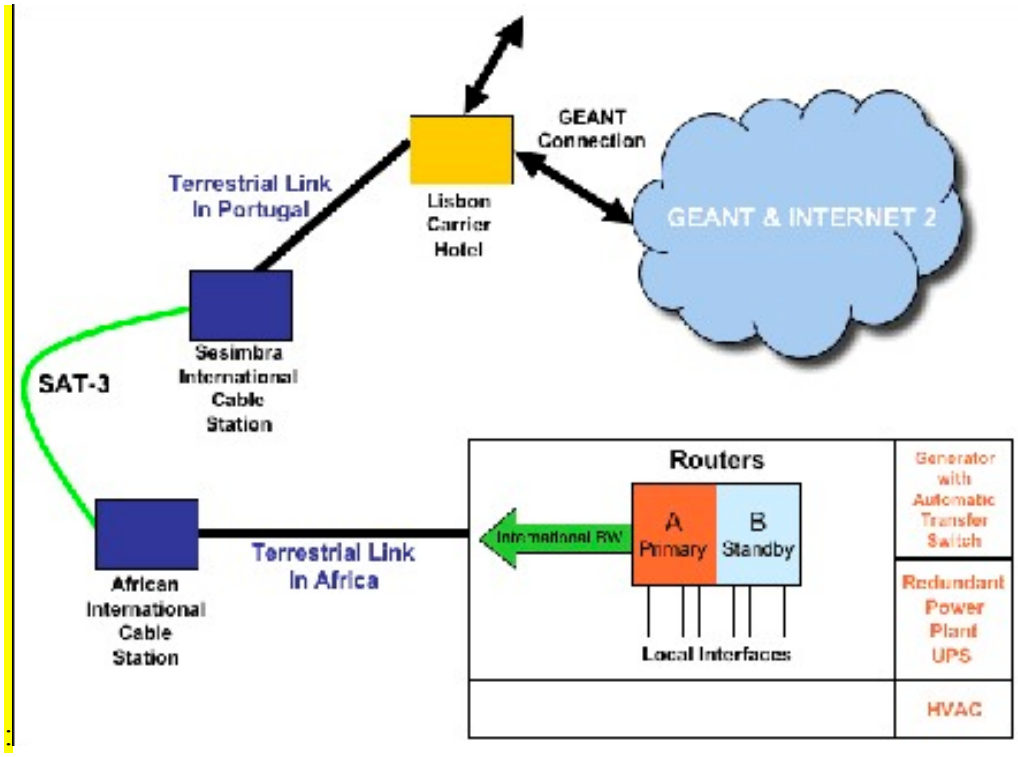
The actual network topology is fairly simple, consisting of the following installations and links between them. The proposed topology for Senegal is:

1. Network operations center in Senegal. The Senegal NOC would be located within the IXC on the campus of the University of Dakar. It would have two Cisco routers (one on standby) with a chassis capable of a bandwidth capacity of one (1) 155MBPS interface plus three (3) gigabit Ethernet interfaces. It would have a 45mbps interface for connection to Sonatel.
2. Sonatel link connecting the Senegal NOC to the cable landing station in Sesimbra, Portugal. This connectivity would be leased from Sonatel at negotiated rates. We would envision entering into a 5-year contract with Sonatel to obtain the most favorable rate for this international facility.
3. Cable landing station in Sesimbra. We would establish a cross-connect between Sonatel and Portugal Telecomm through a CFA (circuit facility assignment) and an LOA (letter of agency) that Sonatel would provide to Portugal Telecomm.
4. Portugal Telecomm link of approximately 15 miles between Sesimbra and the carrier hotel in Lisbon
5. Carrier hotel in Lisbon. We would need to establish a cross connect here through a CFA and an LOA from Portugal Telecomm to GEANT.
6. GEANT connection and connectivity with Internet2. Mr. Dai Davies of GEANT has agreed to allow interconnection of African research and education traffic, up to an aggregate bandwidth of 155 Mbps. Since GEANT connects directly to Internet-2 and other research networks, full connectivity is established.

For a later expansion of connectivity to Ghana, the topology is the same, with the following exceptions:

1. The Ghana NOC would be contained in the Kofi Annan Center. Additional local circuits would connect the Kofi Annan Center to the major university and other institutions in the Accra area.
2. Sonatel would be used to provide the full circuit between Accra and Sesimbra
3. Ghana Telecom would provide the terrestrial back-haul from the cable station to the Kofi Annan Center in Accra.
4. Based upon future pricing of circuits and interface equipment, it may be more efficient to substitute a 155MBPS circuit in place of the two 45mbps circuits between Senegal and Sesimbra, with the one circuit carrying traffic for both countries.

The following diagram illustrates this topology:



Logical network connectivity map

Operation and Management

Network operation would be performed by a combination of organizations.

At the physical level, Sonatel and Portugal Telecom would monitor connectivity for their respective segments of the physical path for both Senegal and Ghana. Ghana Telecom would be responsible for the segment from the cable head end in Ghana to the Kofi Annan Center.

At the network level, monitoring for Senegal traffic would occur at two locations, at NYSERNet in Syracuse and at the newly established NOC in the IXC at the University of Dakar. For Ghana traffic, monitoring will occur at the Kofi Annan Center and at NYSERNet. Monitoring functions will include traffic monitoring, security incident detection and remediation, Project staff and consultants would cooperate with both the NYSERNet NOC and network staffs in Senegal and in Ghana to build a high level of network operations capability within the University that would serve both that institution and other universities' research establishments and other organizations that will be connecting to the network within each country. As mentioned before, a strong NOC would also serve as a launching point for network extensions into neighboring countries.

The National Coordinator

The National Coordinator would be a local organization, composed of stakeholders, that plays a key role in putting the network resource into operation and making available to the broad education community. The National Coordinator would be responsible for

monitoring network utilization, maintaining an inventory and tracking of locations and access, and offering equal and fair use of the bandwidth for education and research. It is expected that beyond the term of this funding, the National Coordinator would be an active partner in assisting other research and education networks that already exist and that would be under development in other countries and regions in Africa.

In-country extension

While the explicit extension of the high speed connectivity to other countries was not a part of this study, we know that in both Senegal and Ghana there are existing fiber paths that connect the main cities and towns of the country on which an NREN could be founded. We would assist local staff in understanding the concept of an NREN and assist them in possible designs for one. The presence of demand by U.S. scientists for such extensions would help guide our priorities in this task.

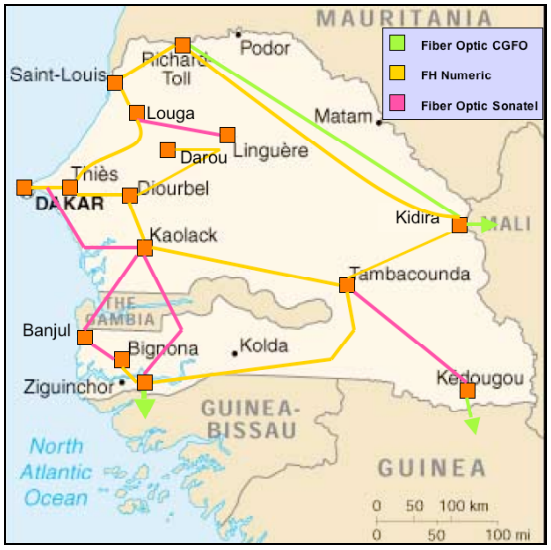


Figure 4. Senegal fiber optic connectivity

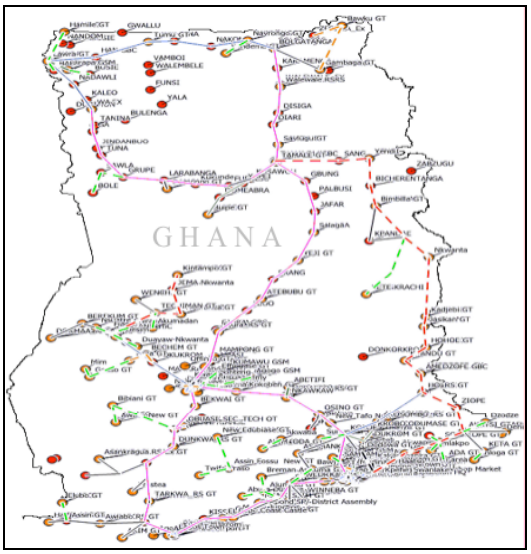


Figure 5. Ghana planned and existing Microwave links as of August 2004

Future extensions

One of the recurring issues that came up in our initial study was that of sustainability. Africa has seen many well intentioned efforts from many international entities, but relatively few that have come to fruition, or more importantly, had a business plan that would ensure the ongoing benefits that the programs were envisioned to establish. Many were of short duration (2-3 years) and therefore of limited impact.

This assessment, given the level of funding that might possibly be made available, is necessarily predicated on connecting two pilot countries, Ghana and Senegal, as discussed. Our goal, however, would be to use this proposal to demonstrate the many benefits a scientific and education community will obtain by being connected to high bandwidth, such that new donors will contribute to connecting additional countries. Any

additional countries to be connected would be subject to being connected to a submarine cable, or be able to be connected to a submarine cable through existing terrestrial optical fiber cable.

Given our selection criteria for most likely to succeed countries, our universe of potential countries to be eventually connected as of this moment consists of Ghana, Senegal, Nigeria, South Africa (via submarine cable), and Mali, Burkina Faso and Mozambique (via terrestrial fiber to a submarine cable-connected country). The World Bank and other donors are planning on constructing an additional submarine cable to serve the east coast of Africa. This system is the East Africa Submarine Cable System (EASSY) and, if successfully completed, would add several more countries to the list.

Project Management

This proposed project would be submitted by NYSERNet, and would operate both from the NYSERNet offices in Syracuse and Albany and from the home-based offices of the Principal Investigator and other senior personnel working on the project. NYSERNet, via the Principal Investigator and senior staff who would be their employees, would have responsibility for the substantive and technical direction of the project.

Because of the size and scope of such an undertaking it is recommended that the management be accomplished via a matrix approach using two Co-PIs. The expertise of the Co-PIs would determine the division of responsibilities but could be structured as followed:

While the Co-P.I.s will collaborate on all matters, the main tasks for which they will act as the primary Point of Contact (POC) are as follows:

PI-1:

1. Manage the substantive liaison of the project in collaboration with the proposing organization, NYSERNet.
2. Work to develop collaborative relationships with other organizations engaged in infrastructure development and programmatic initiatives related to Africa.
3. Manage the technical assistance to the project including:

•Oversee the telecommunications equipment and hardware installation, terminating at the IXC

• Measure and calibrate current networks to determine broadband integration requirements

• Draft and propose MOUs with donors and vendors for integration of configuration including modifications of hardware and software

• Ensure that National Coordinator has been trained to provide reliable connectivity to the research and educational community and to respond to its growth (until National Coordinator is fully trained)

• Provide oversight for the construction of the IXC

4. Involve US universities and researchers (and others) in collaborative research projects with African counterparts.

5. Oversee preparation and submission of all reports, interim and final, for project team and NSF.

PI-1 would be expected to spend, on average, 80% time LOE (32 hours per week) on the project.

PI-1 & PI-2:

1. Draft initial MOUs and then negotiate final MOUs with all stakeholders so that roles and responsibilities are well understood by all.
2. Monitor performance of stakeholders and results of the project per the requirements set out in the MOUs.
3. Manage activities in Africa and in the United States, including:

- site selection & preparation with substantial technical support from NYSERNet and from local consultants.
- preparation of in-country position descriptions.
- recruitment & hiring of in-country personnel.
- management of in-country personnel involving quarterly trips to each country and 'virtual' contact via email and telephone with onsite supervisors between trips. As bandwidth develops, desktop video conferencing will also be utilized.
- Preparation of SOW for, and selection of (with full team input) NREN consultants.
- Management of NREN consultants
- Overseeing the IXC infrastructure and equipment hardware and software procurement and installation

4. Serve as the project's representative to the International Telecommunications Union Development Sector (ITU-D), The Association of African Universities and the New Partnership for African Development (NEPAD)

5. Work with research, education and health communities in country to produce a viable sustainable community for sharing and exploiting the high bandwidth resource.

6. Provide technical leadership and management of the installation and operation of the high bandwidth resource.

All senior personnel would represent the project at pertinent speaking engagements and conferences with a goal of increasing collaborations and extending the network.

Outputs

Deliverables

Deliverables of such a project would be centered upon having a working high bandwidth connection from the targeted countries to the U.S. that is effectively used by the

academic, scientific, and medical communities in the countries. This would be composed of the following results:

- Provision, on a sustainable basis, of a continuous and reliable high bandwidth connection from the United States to an Information Exchange Center (IXC) in the country located on the premises of the lead institution and managed by the National Coordinator coalition of stakeholders.
- Establishment of an Information Exchange Center that functions as an open and neutral, equal access distribution point for academic and research bandwidth, managed in a sustainable manner within the country.
- Establishment or improvement of a National Research and Education Network within each pilot country.
- Encouragement and support of additional bandwidth-intensive initiatives and projects between African and American research and education communities.

Beyond the initial two countries, there should be an identification of partners and the development of draft plans for extending connectivity across Africa to other countries.

Time table

While the pace of implementation of any such project depends upon factors that cannot be controlled by project staff, such as the negotiation of agreements with governments, telecommunications carriers and organizations in the country, we suggest the following timetable as representative of what could be possible based on initiating activity in the first country selected during the first year, and then initiating activity in the second country selected in the second year, while continuing activity in the first country:

Months 1-2:

- initiate close collaborations with Ministers of Finance, Telecommunications and Education, to continue throughout the project
- conclude signed MOU outlining responsibilities of all parties involved
- conclude fiber donation/purchase arrangements for 1st and 2nd country
- complete design of IXC
- choose in-country lead institution (1st country)
- initiate donor collaboration activities

Months 3-6:

- install fiber connection
- install IXC
- train IXC management and operators

Months 7-12:

- assist formation or growth of working NREN consortium
- identify additional consortium membership for NREN development and assist in formation
- extend IXC connectivity (with signed MOUs)

- assist with initiation of scientific collaborations
- conclude signed MOU with 2nd country including selection of lead institution
- manage donor collaboration activities

Months 13-24:
- continue 1st country activities
- complete fiber installation (2nd country)
- design & install IXC
- begin NREN development activities
- extend IXC connectivity
- assist with development of scientific collaborations
- ongoing management of donor collaborations

Months 24-60:
- ongoing overall project management
- ongoing management of donor collaborations
- additional IXC extension installations (with MOUs)
- ongoing NREN capacity building activities
- ongoing assistance with initiating and sustaining scientific collaborations
- ongoing IXC customer population activities to ensure sustainability
- extension to additional countries (non-NSF funding)

Monitoring & Evaluation: Metrics for success

The set of deliverables above could serve as a model template for an overall set of metrics for determining the success of the project over time.

A second set of possible metrics, not easily influenced directly by project activities, could provide measures of success consistent with the primary goal of the project. They include:

- the extent of U.S. African research collaboration
- the growth in U.S. researchers accessing data from African sites
- the number of additional substantive web pages and journal articles produced by such collaboration and access

While much of this data can only be captured anecdotally, there could be an attempt to capture quantitative data to assess the magnitude of the effect that this project will have had, via requirements in the MOUs that organizations would sign to connect to the IXC and through periodic formal queries of the stakeholder community.

Bandwidth Costs

By far the greatest cost item in this proposed project is the cost of international and national bandwidth. The project should endeavor to reduce in-country (national)

bandwidth costs by utilizing WiFi/WiMax wireless technologies where possible. This would still leave a sizeable amount of cost for remaining bandwidth connection. It is here that the approach of the Partnership for Higher Education in Africa could be utilized, which is to negotiate reduced satellite bandwidth costs via the mechanism of a many-country bandwidth-buying consortium. The target for bandwidth costs in Africa for educational purposes has been put at $3.00 per kilobit per month. The Partnership has reduced that cost and is charging its connected institutions less than $2 per kb/month.

Using this model, the project could work with monthly donations from our 'participating partners' in the countries to at least partially cover the cost of the bandwidth, with the remainder made up by NSF funds. It should be noted that current negotiated costs are under $1.00 per kb/month and thus the initial cost for participating partners will be much less than what they are currently paying. As such they would be able to purchase higher bandwidth using their existing budgets.

Over time, as has already been the case, the bandwidth costs will come down to the point that an NSF subsidy should no longer be required and the project would be fully sustainable on its own income.

Management

Although there is significant oversight management from the Co-PIs in the beginning of the program, their participation could be gradually reduced over time as the national employees become fully trained and able to operate the network independently. In addition, employees trained in country A could be used to assist with training in country B and so on, thus removing the need for continued NSF-funded/provided management beyond the timeframe of this project.

Recommendation

During the course of the feasibility study, the project team collected a large number of letters from supporters and partners of a possible project, as well as cost proposals from telecommunications suppliers. Based on the work plan sketched above, cost estimates were made to construct a proposed budget for such a project. This material can be made available to NSF staff upon request.

Based on the results of our in-depth feasibility study, we believe that a project to provide high-speed connectivity to the African research and education community is necessary, important and feasible.

All constraints to achieving such a network can be overcome in an affordable and effective manner. The approach discussed in this study demonstrates that the project can be both sustainable and replicable with African expertise taking over to expand this network throughout Africa. It is likely to have an immense positive effect on improving quality and quantity of collaborations between U.S. and African researchers and educators.