SLAC-PUB-13853

Digital Divide in Sub-Saharan Africa Universities: Recommendations and Monitoring

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Abstract: The Digital Divide prevents Africa from taking advantages of new information technologies. One of the most urgent priorities is to bring the Internet in African Universities, Research, and Learning Centres to the level of other regions of the world. eGY-Africa, and the Sharing Knowledge Foundation are two bottom-up initiatives by scientists to secure better cyber-infrastructure and Internet facilities in Africa. Recommendations by the present scientific communities are being formulated at national, regional and international levels. The Internet capabilities are well documented at country level overall, but this is not the case at the University level. The snapshot of the Internet status in universities in 17 African countries, obtained by a questionnaire survey, is consistent with measures of Internet penetration in the corresponding country. The monitoring of Internet performance has been proposed to those African universities to provide an information base for arguing the need to improve the coverage for Africa. A pilot programme is recommended that will start scientific collaboration with Europe in western Africa using ICT. The programme will lay the foundations for the arrival of new technologies like Grids.

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Keywords: Digital divide, cyber-infrastructure, internet connectivity

Work supported in part by US Department of Energy contract DE-AC02-76SF00515.

1. Introduction

In today's Information Age, an effective cyber-infrastructure and Internet access underpins development and human welfare [1] by strengthening education and training, expanding science, technology and innovation capability, opening up collaboration opportunities with the rest of the world, and generating the knowledge base for decision-making. Poor Internet connectivity prevents many countries in Africa, especially Sub-Saharan ones, from taking advantage of these opportunities. This situation is correlated with most measurements, including both human [2] and economic development [3] that indicates Africa is worse off than other continents and in most cases is falling further behind [4]. Aware of this situation, the African Information Society (AISI) was launched in 1996 as Africa needed a common vision for its quest not only to bridge the digital divide between Africa and the rest of the world but more importantly to create effective digital opportunities to be developed by Africans and their partners, and to speed the continent's entry into the information and knowledge global economy [5]. AISI has partnerships with the United Economic Commission for Africa (UNECA), and the "Partnership for Information and Communication Technologies in Africa" (PICTA) ; UNECA being also a leading member of the Global Knowledge Partnership (GKP).

There are many initiatives from local, governmental, African, European and international organisations to promote, survey and fund networking. Let us cite some examples. The European Commission has developed EuroAfrica-ICT activities and opened opportunities for funded projects of Science and Technology in ICT (Information and Communication Technology). Other examples include the role of the United Nations UNESCO and the International Telecommunications Union (ITU) [6], the International Development Research Centre's (IDRC) reports on Promoting African Research and Education Networking (PAREN), the New Partnership for Africa's Development (NEPAD), and the ATICS survey of 84 leading tertiary institutions in Africa

The different surveys have provided an overall view of the average Internet situation in African countries and the main towns. However the Internet conditions inside a university may differ greatly from this average. Cybercafés may have better Internet connectivity than the neighbouring university. There are initiatives from the Association of African Universities (AAU) in the unit of Research and Education networking to improve the situation. In general the precise situation of Internet connectivity at the university level is not published and may differ from one university to another located in the same country or in different countries. One contribution of this paper is focussed on the actual conditions of internet in universities in which geophysicists are collaborating in international programmes like IHY [7]. The internet conditions have impacts on the research conducted by African scientists and the education of future executives.

Let us take some examples of international projects in which African scientists are involved. Due to the poor Internet connectivity and inadequacy of the cyber-infrastructure in their countries, African researchers, when they don't decide to carry their research out in northern countries, have faced large difficulties in conducting their research and in achieving efficient participation in international projects. As shown in the IDRC report "Brain Drain and Capacity Building in Africa" many have left and do not return. The International Heliophysical Year (IHY) [7], a weather meteorology programme, organized a meeting in Ethiopia in November 2007, focussed on the IHY in Africa. It gathered 103 scientists with 63 scientists from 20 African countries. In the framework of this project, around 40 GPS and 20 magnetometers are installed in African universities and managed by the African scientists and engineers. Their number will increase drastically due to their large range of applications for science, telecommunications and civil sectors. GPS and magnetometer data need to be transmitted in real-time to international or regional databases

and the African scientists need to access them to retrieve other data for their research. Unreliable internet connectivity is a barrier. Another international programme also initiated by the International Union of Geodesy and Geophysics (IUGG), is the electronic Geophysical Year (eGY) 2006-2007. It is devoted to international co-operation for open access to data [8] that is useful only for those who have reliable Internet connectivity.

To address those difficulties, eGY includes also a "bottom-up" initiative [9], to promote better cyber-infrastructure and Internet facilities for universities and colleges in Africa, by using the advocacy of the scientific community at national, regional, and international nsituation for many years, in December 2007 invited in France, for a workshop on the "Internet and Grids in Africa", scientists representing different domains, industrialists, members of Non-Governmental Organizations (NGOs) and a member of the European commission to present the EuroAfrica-ICT programme. The participants originated from 14 countries with 8 African countries [10].

The eGY and Sharing Knowledge Foundation initiatives are based on African scientific communities, and are complementary of other initiatives; some communities participating to all projects. Their bottom-up role is twofold: firstly to motivate and support the scientists in each country (1) to ask their government or organisations for a better Internet for research and for education and (2) to organize themselves to welcome new technologies, secondly to promote a better cyber-infrastructure for their universities towards international organisations. Recommendations [9, 10, 11] to promote reliable Internet and cyber-infrastructure in African countries have been elaborated in both initiatives and have been addressed at national, regional and international levels via the participants and organizers. They are not the first recommendations on this topic; however they come from an inter-country motivated scientific community. In parallel different actions are being taken that are mentioned in this paper.

In the current paper's first section, the context is presented via a table providing the Internet penetration in the involved African countries and the actions conducted by the African Association of Universities. The first objective of those recent initiatives is to provide a quantitative survey of the network in leading universities in each country. The first step, described in section 2, was to create a questionnaire, send it to all the African participants of IHY and then in each country. Preliminary results of the questionnaire analysis are presented in section 3. A second objective, described in section 4, is a continuous monitoring of the Internet in Africa. In section 5, another objective, part of the conclusions of the "Internet and Grids in Africa" workshop [10], is presented. It concerns a pilot programme in collaboration with Europe in order to facilitate scientific collaboration by using ICT Technology at a regional level.

2. Context

Firstly, the context of Internet at a country level is provided in Table 1 by using published parameters, the population [12], the International bandwidth [13], the Internet users in 2004 [14] and the ITU Development Opportunity Index (DOI) [15]. This table points out the scant penetration of the Internet in most African countries and in addition the disparity among the countries. The 18 countries contain about 2/3 of the African population; the countries chosen corresponding to the countries of IHY participants.

However, there are promises of considerably increased fibre connectivity to sub-Saharan Africa. For example there are four projects to bring fibre to East Africa; the East African Submarine Cable System (EASSY), SEACOM, TEAMS and Reliance of India. The goal is to have these cables in place in time for the Soccer World Cup in South Africa in 2010. This should dramatically improve performance for this area. . The launch in mid-December 2007 of the satellite RASCOM-1 is good news for Africa, and could offer new opportunities for Internet connectivity, especially for areas not reachable by terrestrial links.

The creation of Ubuntunet to bring together National research and Education Networks (NRENs) in Southern and Eastern Africa is hoped to help the need for more IXPs [16]. In addition GEANT which already has connections to EuMed in particular Morocco, Algeria, Tunisa and Egypt, has now established a connection to UbuntuNet. There are efforts to establish a transnational network in Western and Central Africa using the UbuntuNet Alliance model; if established, this network will establish an interconnection with UbuntuNet as well as with GEANT and other regional research and education networks.

Country	Response	Population	International bandwidth (Mbps)	International bandwidth / capita (bps)	Internet Users	Internet users/ 1000 capita	Bandwidth (bps)/ Internet User	DOI Rank
Egypt	**Yes**	82,073,660	**3784.0**	**46.10**	1000000	12.18	3784	90
South Africa	**Yes**	43,743,316	881.5	20.15	**1012500**	**23.15**	871	91
Senegal	**Yes**	12,938,350	775.0	59.90	19351	1.50	40050	112
Cameroon	**Yes**	18,569,348	155.0	8.35	6500	0.35	23846	137
Nigeria	**Yes**	**139,070,856**	150.0	1.08	350000	2.52	429	155
Kenya	**Yes**	38,213,024	113.4	2.97	80000	2.09	1417	164
Uganda	**Yes**	31,621,980	100.0	3.16	8000	0.25	12500	152
Burkina Faso	**Yes**	14,866,133	76.0	5.11	14238	0.96	5338	163
Cote d'Ivoire	**Yes**	18,465,326	55.4	3.00	13747	0.74	4031	144
Benin	**Yes**	8,349,959	47.0	5.63	6396	0.77	7348	147
Niger	**Yes**	13,364,797	30.0	2.24	3117	0.23	9625	179
Mozambique	**Yes**	21,379,584	18.5	0.87	25000	1.17	740	169
Ethiopia	**Yes**	78,697,922	10.0	0.13	12155	0.15	823	173
Namibia	No	2,067,433	9.0	4.35	19000	9.19	474	109
Libya	**Yes**	6,208,637	6.0	0.97	Unk	Unk	Unk	101
Congo, Dem Rep	**Yes**	68,554,526	5.0	0.07	Unk	Unk	Unk	150
Congo, Rep	**Yes**	3,926,738	1.0	0.25	Unk	Unk	Unk	154
Liberia	**Yes**	3,390,289	0.3	0.08	Unk	Unk	Unk	Unk

Table 1: Countries polled for the first questionnaire together with their populations, international bandwidth, Internet spread and DOI rank

The top African universities are in South Africa and Egypt, a consistent fact with the internet penetration even if other parameters have to be taken into account [17]. The top university ranking is based on indicators like size, visibility, popularity and number of rich files. Recognising the importance of ICT for teaching, learning and research activities, the Association of African Universities has set up a Research and Education Networking Unit at its Secretariat, as response to an urgent need expressed by its members [18].
The objective of this Research and Education Networking unit is to create synergies among the various ICT initiatives in Africa, with the aim of improving the ICT environment in African higher education institutions and for access to more bandwidth at affordable cost.
Bandwidth cost in Africa is prohibitive; African higher education institutions generally pay more than 50 times than universities in the developed world for the same amount of bandwidth.

In today's world, and this is even truer for Africa, it would be very difficult to assemble in one country the number and variety of skills, as well as the resources required to support competitive research and innovation. Thus, building network infrastructure that can bring

together African scientists and technologists to collaborate and work together on relevant research projects is the only way for Africa to play a significant role in the knowledge-based global economy.

Fortunately, there are several initiatives aiming to establish national and regional research and education networks, with Northern Africa, Southern and Eastern Africa being the locations of the most advanced initiatives, with links to the global research and education network through connections to GEANT, the pan-European REN (Research and Education Network).

The AAU is also involved in activities aiming to create grid computing clusters in several African higher education institutions.

3. Methodology

Even if there are documents on the Internet in Africa [19], mostly they focus on a single country and/or don't describe the actual situation in the universities from the end-user point of view. We therefore composed an initial questionnaire to assess the status of Internet connectivity for scientists and educators in African countries [20]. It was designed to make the questions as clear as possible and where feasible used multi-choice answers to simplify the input and later analysis.

The questionnaire was divided into 5 sections:

- Personal details of the responder (name, institution, email, duties and interests)
- National Internet Facilities
- Institution Internet Facilities
- Problems and priorities
- Suggested next steps.

The initial questionnaire was sent to participants at leading universities or research sites in 19 African countries, prior to the IHY meeting in Ethiopia [7]. We received responses from 17 of the 19 countries. About 12 of the responses were by email prior to the start of meeting. The remainder were obtained from one-on-one face-to-face discussions between the participants and the questionnaire developers attending the IHY meeting. The tentative results from this first questionnaire were presented at the IHY meeting in Ethiopia [22] and at the "Internet and Grids in Africa" workshop in France [10, 11]. Based on the analysis of the results and feedback from the initial questionnaire and the one-on-one discussions, a second questionnaire was developed using email between four designers. This increased the use of multi-choice, simplified the questions, and added extra questions.

An early version of the second questionnaire [9] was tried out in person with an African attendee at the Internet and Grids in Africa workshop. The questionnaire was further modified and emailed to a small group of early participants to solicit their feedback and allow further improvements. To assist in explaining the purpose of questions and the type of answers solicited, examples were also enclosed in the second questionnaire mailing. These examples were real results received from two or three early participants.

We expect to soon have a contact in each major African country to enable an overview of the cyber-infrastructure conditions, especially in the major universities.

3. Analysis

We received results from universities in 17 of the 19 African countries, including: Algeria, Benin, Burkina Faso (2 responses), Cameroon, Congo Democratic Republic (RDC), Republic of Congo (RC), Egypt, Ethiopia, Kenya, Liberia, Libya, Mozambique, Niger, Nigeria, Senegal, South Africa (3 responses), Uganda.

The main quantitative results from the first questionnaire were:

- Each university had tens of 1000's of students, with typically around 1000 or so staff

- The best had 2 Mbits/s Internet access to the outside world
- The worst were using dial up 56kbps
- Often the access was restricted to faculty only.
- Only in 6 countries (Burkina Faso, Cameroon, Egypt, Ethiopia, Mozambique, South Africa) of the 18 countries are most universities connected. For other countries it varies from 5% to 50% of universities have Internet access.
- Other of the 17 countries only Burkina Faso, Egypt, Kenya and South Africa have a National Research and Education Network (NREN) [21].
- Four countries had Internet connectivity in the capital only (Ivory Coast, Niger, Congo Dem. Rep., Congo Rep.)
- South Africa had access almost anywhere people could afford it.
- Most respondents wanted more bandwidth and reduced costs.
- Reliable power was often cited as a major problem.
- Suggestions were to increase competition, remove monopolies, open markets to international service providers.

It was also interesting that most of the email respondents used commercial email services such (e.g. gmail) rather than the email of their university/institution.
The answers are consistent with the Internet penetration (Table1). This analysis is just a snapshot of few universities. It permits to the scientists involved to become conscious of the university situation at a continental scale and to decide to organize themselves at a regional level.

One issue is the reliability of the internet, i.e. difficulty to have it available on a 24h basis, seven days a week basis. The second issue is its primitive speed. The following examples give Some numbers to point out the difficulty of African scientists. The effect of being limited to 100kbits/s is that it takes over a minute to transfer a typical 2MByte image from today's pocket 8 Megapixel digital camera, or almost half an hour to transfer the 22 MByte postscript version of reference [24]. An AVI 640x480 pixel movie file takes ~700kbits/s to play in real time. A 700MByte CD would take 15 hours to download 10 100kbits/s. Compare this with typical developed world university connections of 1 Gbits/s where it takes less than 10 seconds to download the CD and the disadvantages experienced by researchers in Africa are apparent.

4. Monitoring of Internet Performance for Africa

The second goal has been to provide continuous active end-to-end monitoring of African Internet connectivity. To accomplish this we turned to the PingER Project [23][24]. This was started in 1995 to provide active end-to-end network performance measurements for the High Energy Physics (HEP) community. The extra measurement traffic added to the network is low (~100bit/sec for each monitor/remote site pair). At the turn of the century, it was extended to gather information related to quantifying the Digital Divide, in particular how the Internet performance differs between developed and developing nations, where is most assistance needed, what are the baselines, trends etc. It now includes measurements to over 150 countries that between them contain over 99% of the world's Internet connected population. The information gathered is archived and analyzed and freely available via the web. The results are important for trouble-shooting, planning, setting expectations, justifying and seeing the effects of upgrades and for presenting to policy making and funding bodies.

We extended the PingER project to improve the coverage for Africa by identifying the contact in each African university involved in the IHY and eGY. We proposed to them to monitor their network, and in several cases (Congo Dem. Rep., Burkina Faso, Congo Rep.,

Senegal, South Africa) to make measurements from their site. As a result of this, in 2007, we extended the measurements from 32 to 45 of the 54 African countries.

Presentations [25] on the results for Sub-Saharan Africa were given at the IHY meeting in Ethiopia and the Internet and Grids in Africa meeting in France. Following these presentations, we put together a more complete case study [4] of the situation in Sub-Saharan Africa. It discusses the situation at the start of 2008, in terms of available infrastructure, capacity, costs, tariffs, education, brain drain, development, conflict, corruption and opportunities. It then compares African Internet performance measured by PingER and compares various PingER metrics such as Round Trip Time (RTT), loss, jitter, throughput etc. with the rest of the world and between sub-regions in Africa. It compares these metrics with various human and economic development indices. It also looks at the routing and bandwidth utilization in Africa, and goes on to show examples of the effect of the poor African performance and suggests some possible remedies [26].

The throughput is derived from the RTT and loss using the formula:

TCP throughput (kbits/s) = 1460*8 / (RTT * sqrt(loss))

where the RTT is in msec [27].The PingER-derived throughput results (see Figure 1) show that not only is Africa many (~20) years behind developed regions such as Europe but is falling further behind each year. Also the throughput of about 100kbits/s is less that that typically available to a residence in developed countries.

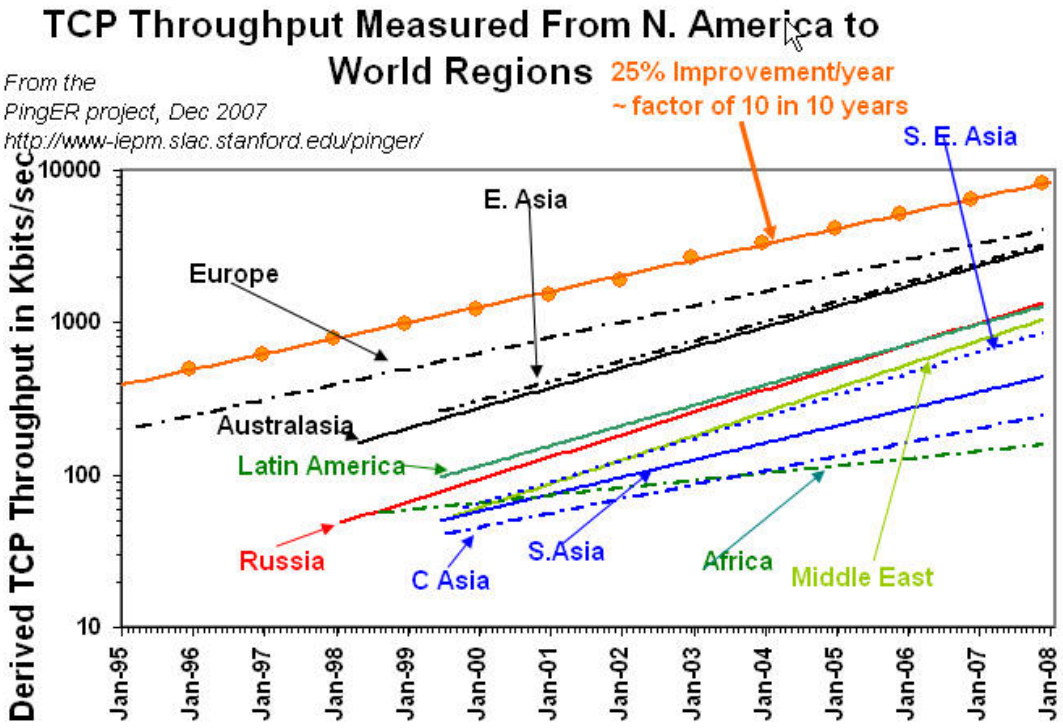

Figure 1:Derived throughput as a function of time seen from ESnet sites to various regions of the world. The lines are exponential fits to the data.

The general observation of Africa having the poorest Internet connectivity of any region is reflected in almost all PingER measured metrics (see [4] and [24]) including loss, jitter, unreachability (all pings of a measurement set fail), and the Telecommunications Industry's Mean Opinion Score (MOS) voice-quality metric. As an example one can view a map of the measurements of jitter in 2007 in Figure 2 [28]. It is seen that the worst regions are Africa, Central Asia, and parts of South Asia with Africa being the worst. Similar results are also observed for loss (see Figure) [29].

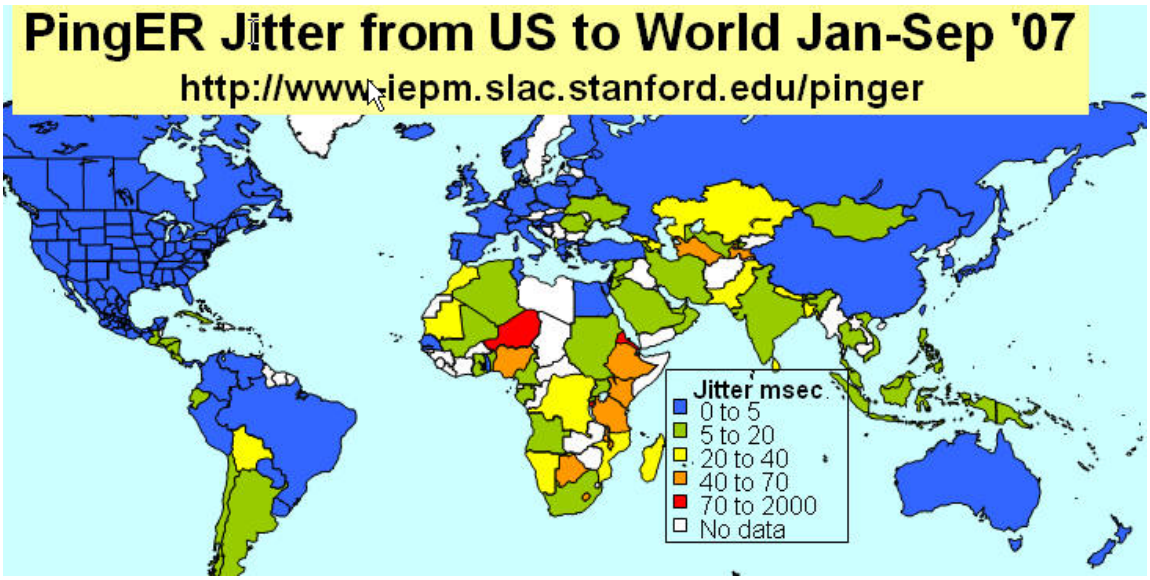

Figure 2;Jitter measured between January and September 2007 from t he US to countries of the world.

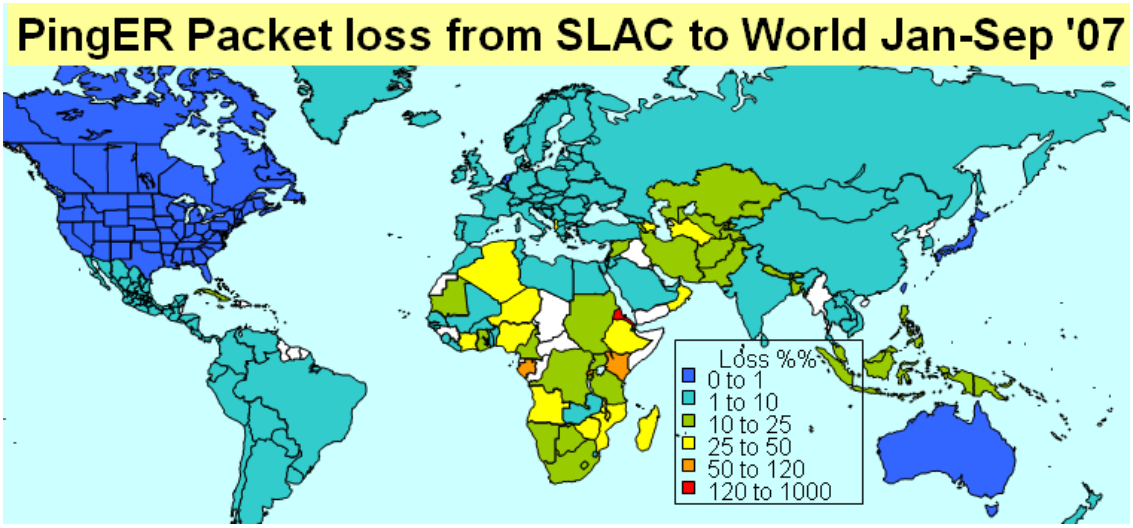

Figure 3:Jul-Sep '07 median average monthly packet loss per mil seen from SLAC to the world.

We also compared PingER results with eight Human and Economic development indices. From this list of indices we selected the HDI [2] and the ITU Digital Opportunity Index (DOI) [3] for further analysis and comparisons with PingER measurements since these indices are enriched with most of the important factors, cover a large number of countries and are reasonably up-to-date. Here we focus on the PingER throughput measures since they incorporate both losses and RTT and throughput is critical for many developing applications. Figure 4 below shows that there is a strong correlation between the normalized derived PingER throughputs and the DOI [30]. Similar correlations are also seen for jitter and loss

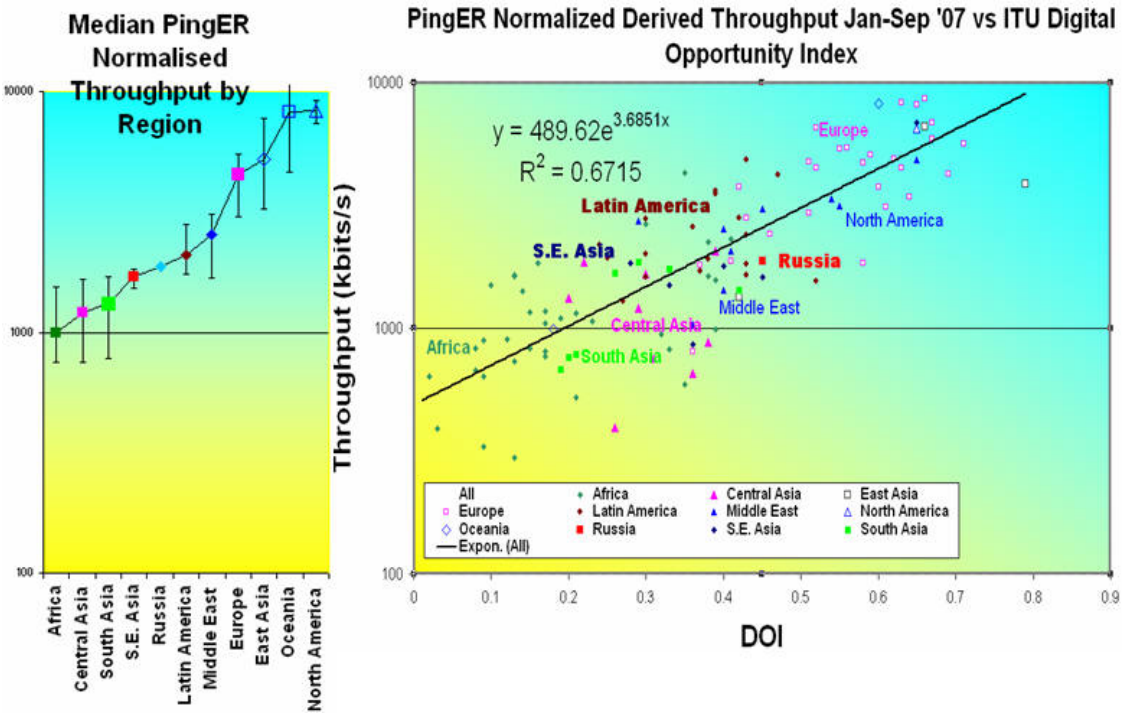

Figure 4: PingER-derived throughputs normalized for RTT versus the DOI. Countries are colored according to their regions.

Figure 5 below shows an example of the PingER throughput versus the HDI. It is seen that the European countries have the best performance (an order of magnitude better than East Africa) and East Africa the worst. Within Africa, North Africa is the best off.

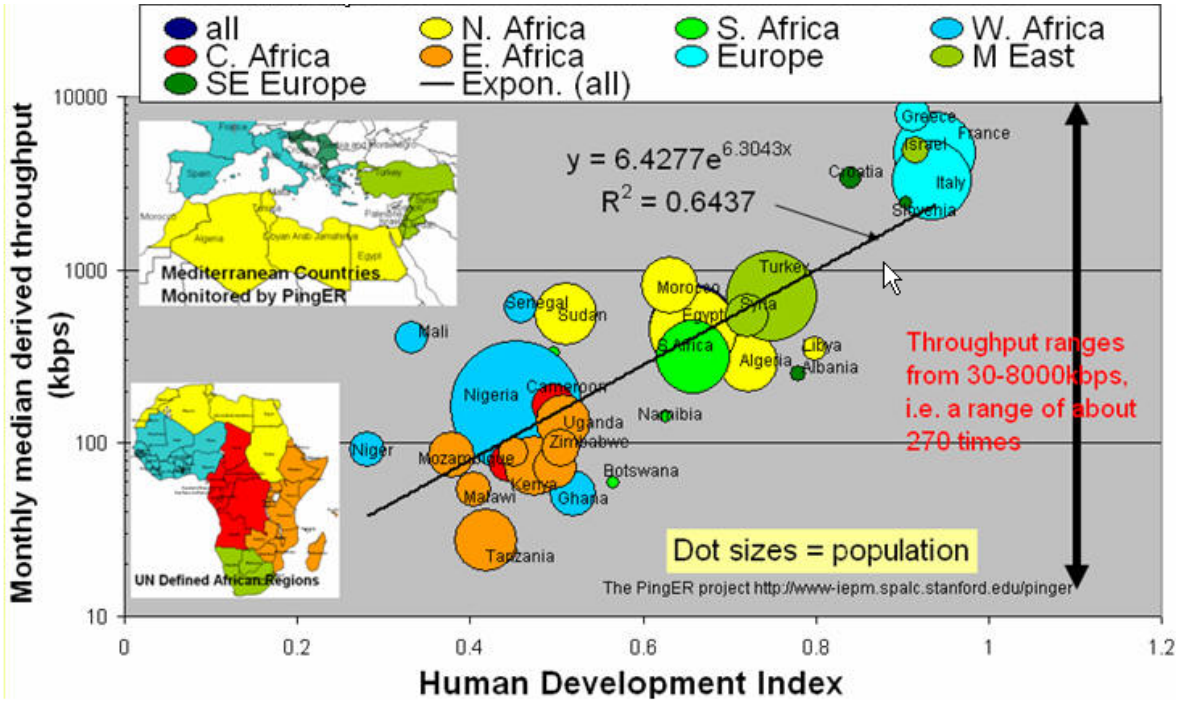

Figure 5: Throughput vs. UN Human Development Index for African countries compared to countries around the Mediterranean.The area of the dots is proportional to the population of the country.

We also looked at the routing of Internet traffic from a host in South Africa to hosts other African countries. It showed that apart from hosts in South Africa, Botswanaland and Zimbabwe which have direct routing, all others go via Europe or the US or both. This not only results in extended RTTs but also means the traffic is subsidizing expensive

international carriers. There is an immediate need for IXPs to be established to provide connectivity between African countries to assist in overcoming the routing situation.

5. Pilot Programme

During the workshop of the Sharing Knowledge Foundation, the development of scientific collaboration by using ICT was considered as an essential point. The needs for ICT resources have already been identified in many sectors like in the field of human and animal health, environment, natural disaster prediction and business. However for the scientific communities working on a common programme, like the one in geosciences, from an ICT point of view, it is easier for them to collaborate with Northern countries than with neighbour African countries located in the same region due to a reliable internet connectivity.

A pilot programme is recommended for starting scientific collaboration with Europe at regional level by using ICT and then for anticipating the arrival of new technology like Grids. A Grid initiative has been started by Hewlett-Packard (HP) in the framework of an UNESCO programme. It concerns five universities located in Algeria, Ghana, Nigeria, Senegal and Zimbabwe, respectively. This project is centred on the local Grid.

The goal of the pilot programme is to deploy this new technology at a regional level like the ones existing in Europe, Mediterranean Area, and Latin America. The experience of the HP-UNESCO programme will be an important input to the pilot programme. At the beginning the pilot programme starts with 6-7 western African countries that participated in the Sharing Knowledge Foundation workshop. In each country they will create a small team with scientists and engineers to cover scientific and technical fields. They are working in collaboration with teams involved in the European Grid project, EGEE. The example of Grid implementation in other countries will be used to define the different steps of the work before submitting a proposal at the European commission for the deployment of a Grid infrastructure in Sub-Saharan Africa. Training and local pilot projects will be part of this programme.

6. Conclusions

The preliminary survey confirms that even in the best cases the Internet capacities in the selected universities are only comparable to that of a broadband connection at home in North America, Europe or Japan. In many cases the capacity is so bad only faculty are enabled to use it. Even in a country the situation is uneven and differs from one university to the other. The better African universities, in the 17 countries responding, should have high-speed connections to the Internet that should serve tens of thousands of students and faculty; this is not the case. This university situation is a major drawback for research and education.

To improve the situation, the recommendations on cyber-infrastructure in Africa, stated by African scientific communities during the eGY and Sharing Knowledge foundation meeting, are being disseminated at different levels – national, regional and international. It is too early to see the results.

To track the trends and measure the impact of new initiatives we have proposed to monitor the Internet performance to at least one site per African country and to extend the number of monitoring stations in Africa. Compared to the various economic and human development indices, the significance PingER's Internet measurements to characterize a country's development is due to the fact that its data is current (up-to date), it is less likely to be subjective, and it is much easier to gather.

In parallel, a pilot programme has been recommended to facilitate the scientific collaboration by using ICT on a regional base and to anticipate the arrival of new technology like Grids. It will be carried out in coordination with Europe.

Bringing the Internet in Africa to the level of other regions of the world, both for the general population and for the most advanced University, Research and Learning Centres, it must be considered as one of the most urgent priorities.

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[26] "Possible Remedies to Promote the Internet in Developing Regions", Les Cottrell, available at: https://confluence.slac.stanford.edu/display/IEPM/Possible+Remedies+to+Promote+the++Internet+in+Developing+Regions
[27] M. Mathis, J. Semke, J. Mahdavi, T. Ott, "The Macroscopic Behavior of the TCP Congestion Avoidance Algorithm",Computer Communication Review, volume 27, number 3, pp. 67-82, July 1997,.
[28]more on the effects of jitter see http://www.slac.stanford.edu/comp/net/wan-mon/tutorial.html#jitter
[29] For more on the effects of loss see http://www.slac.stanford.edu/comp/net/wan-mon/tutorial.html#loss
[30] More on http://www.slac.stanford.edu/comp/net/wan-mon/tutorial.html#derive