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Quantifying the Digital Divide: A Scientific Overview of Network Connectivity and Grid Infrastructure in South Asian Countries

Shahryar Muhammad Khan [1,2], R Les Cottrell [1], Umar Kalim [2] and Arshad Ali [2]

[1] Stanford Linear Accelerator Center, United States
[2] NUST Institute of Information Technology, Pakistan
{shahryar, cottrell}@slac.stanford.edu, {umar, arshad.ali}@niit.edu.pk

Abstract

The future of Computing in High Energy Physics (HEP) applications depends on both the Network and Grid infrastructure. South Asian countries such as India and Pakistan are making significant progress by building clusters as well as improving their network infrastructure However to facilitate the use of these resources, they need to manage the issues of network connectivity to be among the leading participants in Computing for HEP experiments. In this paper we classify the connectivity for academic and research institutions of South Asia. The quantitative measurements are carried out using the PingER methodology; an approach that induces minimal ICMP traffic to gather active end-to-end network statistics. The PingER project has been measuring the Internet performance for the last decade. Currently the measurement infrastructure comprises of over 700 hosts in more than 130 countries which collectively represents approximately 99% of the world's Internet-connected population. Thus, we are well positioned to characterize the world's connectivity. Here we present the current state of the National Research and Educational Networks (NRENs) and Grid Infrastructure in the South Asian countries and identify the areas of concern. We also present comparisons between South Asia and other developing as well as developed regions. We show that there is a strong correlation between the Network performance and several Human Development indices.

Introduction

The last decade has seen tremendous improvements in the Internet infrastructure with users experiencing, lower packet loss, Round Trip Times (RTT) and increased throughputs. PingER[1] measurements have been used for over a decade for monitoring Internet connectivity worldwide and more recently, the focus has shifted to the developing and under-developed regions, especially Africa and South Asia for the purpose of quantifying the Digital divide.

In this paper we compare the network connectivity of South Asia with the rest of the world regions, performance of South Asian networks as seen from US and Europe, network routing within South Asian countries, Mean Opinion Score (MOS) [2] of South Asian Countries, current status of Network and Grid infrastructure in South Asian Countries and Comparison of Network performance with Human Development Indices.

South Asia as Compared to the rest of the World Regions

World Internet Statistics [3] show that for most of the developed world (US and Canada, W. Europe, Japan, Taiwan, S. Korea, Singapore and Australia/New Zealand (Oceania)) typically 40% or more of the people have Internet connectivity while for S. Asia it is less than 5%, i.e. typically a factor of 10 less.

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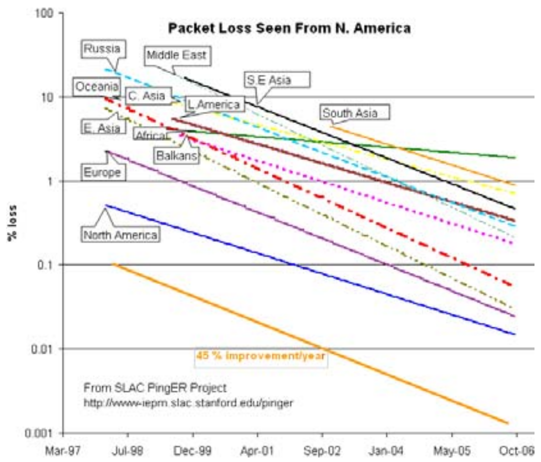

Figure 1 Packet Loss Seen from N. America

Figure 1 shows the packet loss to various regions of the world as seen from N. America. Since losses are usually dependent on last-mile connections they are fairly distance independent so no attempt has been made to normalize the data for distance. It is seen that the world divides into two major super-regions: N. America, Europe, E. Asia and Oceania with losses below 0.1%, and Latin America, C. Asia, Russia, S.E. Asia, S. Asia and Africa with losses > 0.1% and as high as a few per-cent. All countries are improving exponentially, but Africa is falling further behind most regions. In general, the packet losses have declined by almost 45% each year. However the progress for Africa and South Asia has been much slower.

The minimum RTT shown in Figure 2, is distance dependent. The RTT to North America is artificially low as the measurements are made from United States ESnet[4] sites. The dotted lines show the monthly variability. The large step for S. Asia in 2003 is the result of gradual shift from satellite to fiber. Central Asia (also Afghanistan) has hardly moved in its minimum RTT since it continues to use geostationary satellites

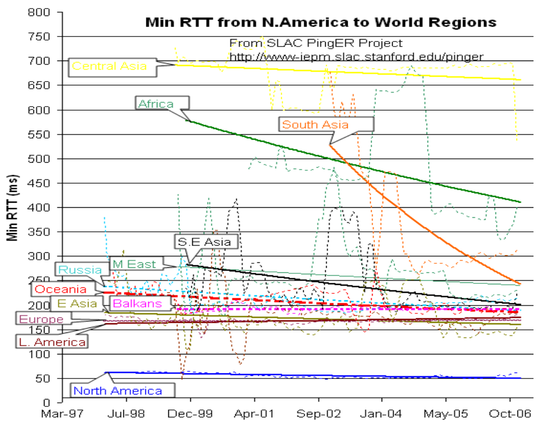

Figure 2 Min RTT from N. America to World Regions

. Africa and S. E. Asia are improving Latin America took a huge step down in RTT at the end of 1999 going from mainly satellite (>500ms) to 200ms (i.e. mainly landlines). S.E. Asia looks like a gradual improvement. For most of the other regions the improvements are marginal.

Figure 3 shows the unreachability of world regions seen from the US. A host is deemed unreachable if all pings of a set fail to respond. It shows the fragility of the links and is mainly distance independent (the reasons for fragility are usually in the last mile, the end site or host). Again the developed regions US and Canada, E. Asia, and Oceania have the lowest unreachability (< 0.3%) while the other regions have unreachability from 0.7% to 2%, and again Africa is not improving, with S. Asia having the second worst unreachability.

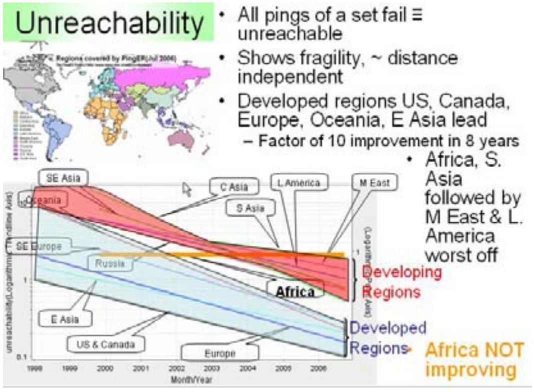

Figure 3 Unreachability of World Regions from US

The graph in Fig. 4 shows the jitter or variability of RTT for world regions seen from the US. The jitter is defined as the Inter Quartile Range (IQR) of the Inter Packet Delay Variability ($IPDV_i = RTT_i - RTT_{i-1}$) where i is the packet number. The Jitter is relatively distance independent; it measures congestion, and has little impact on the Web and email. It decides the length of VoIP codec buffers and impacts streaming. We see the usual division into developed versus developing regions.

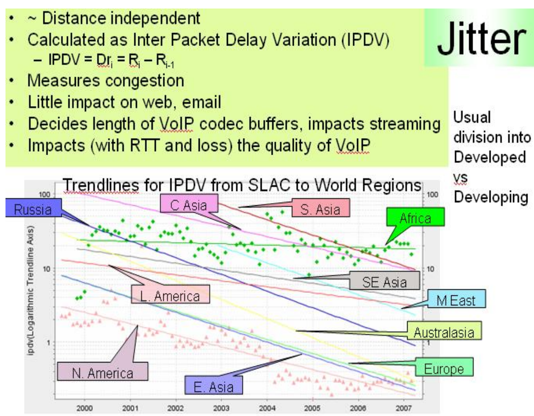

Figure 4 Jitter of World Region seen from US

South Asia as seen from US and Europe

Figure 5 shows time series of the daily averaged derived TCP throughputs (in kbits/s) to S. Asia from SLAC. The TCP Throughput is calculated using Mathis Formula*.It can be seen that there are large fluctuations. These fluctuations are a characteristic of congested lines (typically the last mile). At weekends when people are not at work, there is less congestion and better throughput. Also at day time when more people are using the network there is more congestion. It is also seen that the countries divide into two. India, Pakistan, Sri Lanka and the Maldives have better throughput 400-1200 kbits/s compared to Nepal, Bangladesh, Bhutan and Afghanistan with between 75 and 400 kbits/s.

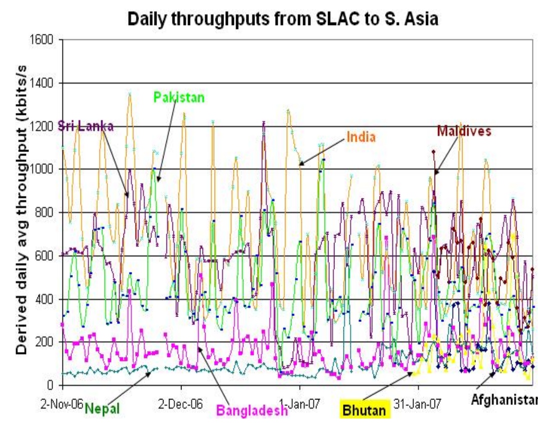

Figure 5 Daily Averaged throughputs from SLAC to South Asia

The minimum RTTs (seen in the Figure 6 below from CERN/Geneva Switzerland) are acceptable for India and Pakistan. For Afghanistan they are large (dreadful or over 500ms) since the connections are via geostationary satellite(s). The routing for Sri Lanka, Bangladesh, Nepal and Bhutan is non-optimal so the RTTs are poor or very poor.

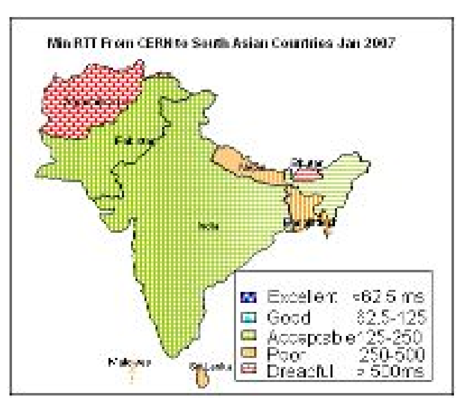

Figure 6 Min RTT from CERN to South Asian Countries January, 2007

The map in Figure 7 shows the packet losses. These are more distance independent than RTTs. Once again it is seen that India, Pakistan, Sri Lanka and the Maldives have

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*Mathis Formula
$Rate < (MSS/RTT)*(1 / sqrt(p))$
where:
Rate: is the TCP transfer rate
MSS: is the maximum segment size (fixed for each Internet path, typically 1460 bytes)
RTT: is the round trip time (as measured by TCP)
p: is the packet loss rate.

acceptable losses (< 2.5%). While Afghanistan, Bangladesh, Bhutan, and Nepal have poor to very poor losses.

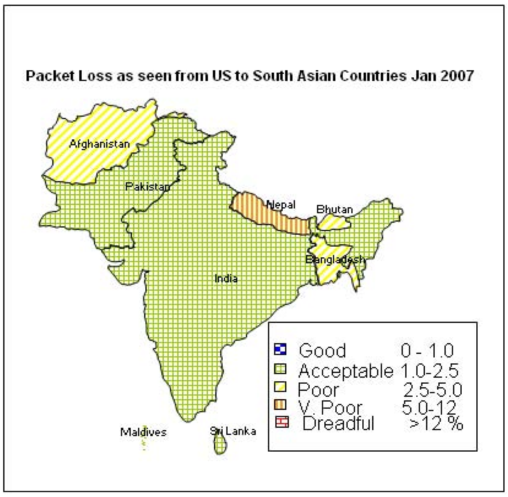

Figure 7 Packet Loss as seen from US to South Asian Countries January, 2007

Figure 8 shows the average and minimum RTTs per site (the dots), and the aggregate values of average and minimum RTTs for each S. Asian country as seen from SLAC. The dots show the dispersion in the values for a country as well as the number of sites for each country. It is seen that Afghanistan is the worst off (largest values) country in RTT as might be expected since it is using geostationary satellite links. This is followed by Bhutan, Bangladesh and Nepal. The best country is India closely followed by the Maldives, Pakistan and Sri Lanka.

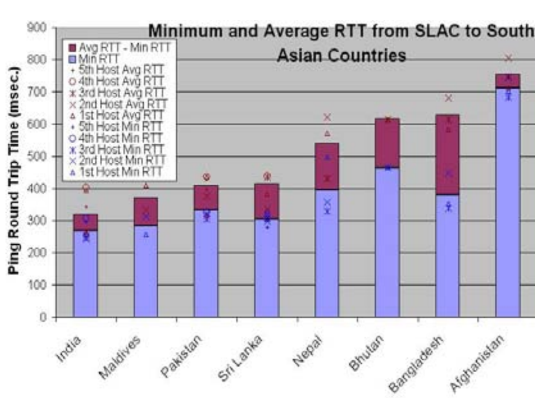

Figure 8 Average and Min RTT from SLAC to South Asian Countries

Routing Within South Asian Countries

We have PingER monitoring stations in India, Pakistan and Sri Lanka. Reverse traceroute servers are deployed at PingER monitoring stations which helps us understand how India and Pakistan are connected with different countries of South Asia. India's VSNL provides Internet Service to Nepal and Bhutan. In the case of Bhutan it first goes from India to Hong Kong, then returns to India and then eventually goes to Bhutan. Afghanistan is served by a satellite provider from DESY, Hamburg, Germany (part of the Silk Road project), so the traffic goes to Germany via satellite and then is beamed back to Afghanistan via satellite. Between sites in Pakistan or between sites in India traffic goes relatively directly without leaving the country. Figure 9 shows a map of routing as seen from India to other South Asian Countries.

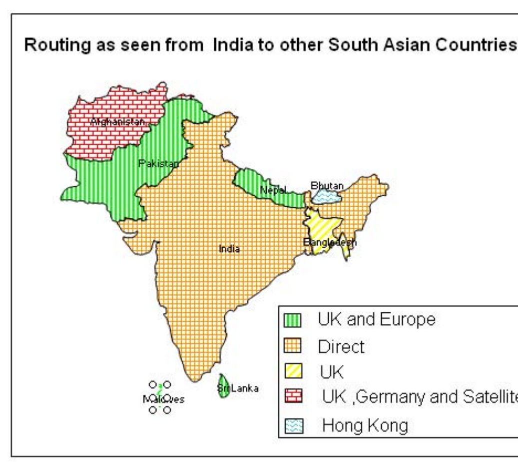

Figure 9 Routing as seen from India to other South Asian Countries

Traffic from Pakistan to India goes via the US or Canada; to Bangladesh goes via the US and the UK. Although Bangladesh now has access to SEMEW4 some of the sites in Bangladesh are still on satellite and the satellite service is provided by a number of European Countries. Traffic from India to Pakistan goes via Europe; to Bangladesh goes via the UK. Figure 10 shows a map of routing from

Pakistan to other South Asian Countries. Due to all the indirect routing the average RTT from India and Pakistan to other South Asian countries is below the acceptable mark.

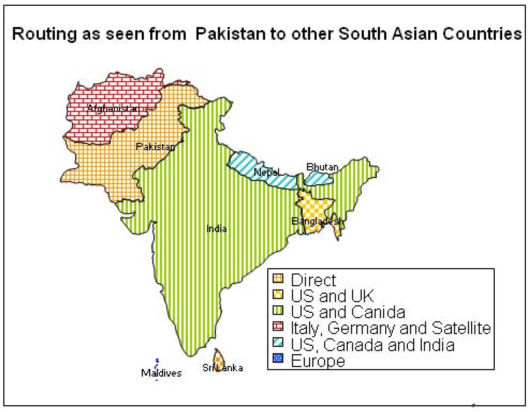

Figure 10 Routing as seen from Pakistan to other South Asian Countries

MOS (Mean Opinion Score)

The telecommunications industry uses the Mean Opinion Score (MOS) [3] as a voice quality metric. The values of the MOS are: 1= bad; 2=poor; 3=fair; 4=good; 5=excellent. A typical range for Voice over IP is 3.5 to 4.2 [6]. In reality, even a perfect connection is impacted by the compression algorithms of the codec, so the highest score most codecs can achieve is in the 4.2 to 4.4 range.

There are three factors that significantly impact call quality: latency, packet loss, and jitter. We calculate the jitter using the Inter Packet Delay Variability (IPDV)

Most tool-based solutions calculate what is called an "R" value and then apply a formula to convert that to an MOS score. Then the R to MOS calculation is relatively standard. The R value score is from 0 to 100, where a higher number is better. To convert latency, loss, and jitter to MOS we follow Nessoft's [5] method. Figure 11 shows the Exponentially Weighted Moving Average (using $EWMI_i = alpha * EWMI_{i-1} + (1 - alpha) * Obs_i$ where $alpha = 0.7$ and $EWMI_1 = Obs_1$) for the MOS as seen from the W. Coast of America (SLAC). MOS values of one are reported for heavy loss (loss > 40 %).

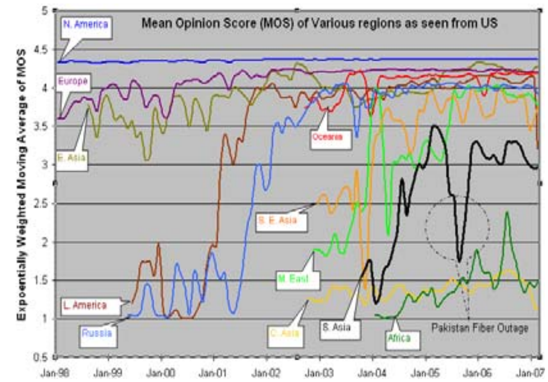

Figure 11 Mean Opinion Score (MOS) of various regions as seen from US

It is seen in above graph that Russia and Latin America improved dramatically in 2000-2002. Much of Latin America and Russia moved from satellite to land lines in this period. It can be seen from the above plot that VoIP ought to be successful between SLAC and the US, Europe, E. Asia, Russia and the Middle East (all above MOS = 3.5). S. E. Asia is marginal, S. Asia people will have to be very tolerant of one another, and C. Asia and Africa are pretty much out of the question in general. The spike in South Asia is the result of fiber outage in Pakistan [7] around June 2005. In June 2005, we were monitoring 12 South Asian sites out of which 7 were from Pakistan so it has a great effect on performance of South Asia.

The graph below (Figure 12) shows the Mean Opinion Score (MOS) seen from US to South Asian countries. In general South Asian counties can be divided into two group with India, Pakistan, Sri Lanka and Maldives performing comparatively good (Voice Conference possible but voice quality not that good) whereas Afghanistan, Bangladesh, Nepal and Bhutan are dreadful and Voice conference from US to these countries is not possible. We have good coverage in India and Pakistan so the results are a good indication of the overall performance. The spike in MOS for Pakistan in July 2005 is the result of fiber outage to Pakistan.[6] The number of sites for Sri Lanka increased from 2 to 6 in Jan 2007 so the results after Jan 2007 is a better indication of the overall performance for Sri Lanka. Before Jan 2007 we were monitoring two hosts in Sri Lanka (University of Peradeniya performing very bad with average RTT > 500 ms, and LK Domain Registry performing reasonably good Average RTT < 350 ms). Afghanistan is stuck with satellite connectivity and the land locked countries Nepal and Bhutan have limited fiber connectivity, so they mostly lie at the bottom.

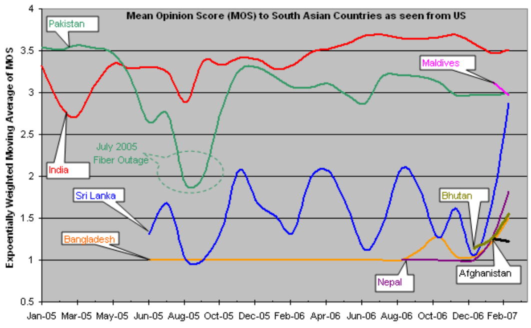

Figure 12 Mean Opinion Score (MOS) to South Asian Countries as seem from US

Current Status of South Asian Countries

Afghanistan

We have three sites in Afghanistan. It is difficult to get reliable sites in Afghanistan. For example the Kabul University host is a firewall that does not have stable power and so is usually turned off at night. Also these sites have minimum RTTs greater than 700 ms which indicates that they are all on satellite. The Kabul host is connected via the Silk Road [8] satellite that passes through DESY, Germany. The other two are connected via Telia a European ISP. On March 10, 2003, Afghanistan went live on the Web which was previously banned under the Taliban rule. The Internet infrastructure in Afghanistan is immature and the pricing for internet access is quite high.

Bangladesh

SEMEW4[35] has greatly affected the internet connectivity of Bangladesh Before this Bangladesh relied on VSAT for Internet connectivity.

Most of the sites now have moved to fiber but some of them are still on satellite. We used our HostSearcher [9] tool which searches for sites on Google. Out of 20 sites that we located in Bangladesh 3 had min RTT > 500 ms indicating that they are on satellite. Bangladesh has now got 2 STM-1 links with MCI and SingTel.

There are three sites at Bangladesh which host PingER monitors. BRAC University is on satellite. Dhaka University of Engineering and Technology and the other university are connected through fiber but they use satellite as there backup link.

Bhutan

We are monitoring two hosts in Bhutan: the Royal University of Bhutan (RUB) and Bhutan Telecom Limited; both of these are served by satellite from a UK Satellite provider**.** The Royal University of Bhutan is also building RUBWAN[10], a fiber network linking all the constituent colleges.

India

In the Fall of 2006 there were demonstrations of advanced networking at 622Mbps at CHEP 2006 [11] in Mumbai, organized by the C-DAC [12], TIFR [13], on the US side by IEEAF [14] , ICFA/SCIC [15] members, UWash/PNWGP, for Japan the WIDE Project at Keio University, and others. This was followed by a workshop organized by the Ministry of Communications and Information Technology (MCIT) [16], ERNET [17], C-DAC, TIFR, and the National Knowledge Commission [18]. Following this and advice provided by ICFA/SCIC members, Internet2 [19], the IEEAF, the Knowledge Commission of India issued a recommendation to create a Knowledge Network.

India has rapidly moved forward towards advanced network infrastructure (i.e. a backbone like Abilene and possibly CENIC-like organization which they refer to as SPV: special purpose vehicle). The Indian Prime Minister has accepted the National Knowledge Commission recommendations and efforts are on to create a CENIC like organization to provide the shared gigabit optical fiber backbone to all RENs including ERNET, Garuda, science and technology research network and medical research and education network among others.

Below are shown the current deployment of the Garuda and ERNET networks in India.

Figure 13 Deployment of the Garuda and ERNET networks in India

Maldives

We have two sites in Maldives, (the traceroute results showed that the second last hop was through Italy). In January, 2007 Maldives connected to SMW4 fiber as a result of collaboration between Dhiraagu [20] and Telecom Italia Sparkle [21].

Nepal

Recently Nepal Telecom struck a deal with Indian VSNL [22] so now the land locked Nepal will have access via optical fiber. It is in test (April 2007). The complete project will (expected project execution date, end 2007) run 900km East-West along the Anriko highway with 16 nodes between Kathmandu and Tatopani. There are plans for a 115km link to China which will provide a second international access link. But still most of the sites are on VSAT (Satellite). Some initial projects are being planned for the new Fiber (the first one will probably use IPv6) There is also a Nepal Wireless Project using 802.11b to introduce villagers to IT.

Pakistan

PERN [23] (Pakistan Education and Research Network) is funded by the Pakistan Higher Education Committee (HEC) [24] and is a nationwide educational intranet connecting premiere educational and research institutions of the country. The network provider for PERN is NTC [25]. In 2002 PERN had 2Mbps backbone links between major cities. The current (Jan 2007) network design was put in place in 2005 and consists of three nodal points at Islamabad, Lahore and Karachi interconnected by 50Mbps. Each PoP has international access. Educational institutions are connected by a minimum of 2Mbits/s. .

All land based Internet connectivity is via the Pakistan Internet Exchange (PIE) in Karachi where the fiber comes ashore. PIE in turn is managed by Pakistan Telecommunication Company Limited (PTCL) [26]. PTCL has excess capacity on its long haul international fibers.

Pakistan's sole under sea optical fiber link in 2005, called Southeast Asia, Middle East and Western Europe-3 (SEAMEWE-3), stopped working for about 12 days due to a fault from 27th June to the 8th of July 2005. This disruption halted the global connectivity of almost 10 million internet users in the country.

Recently Pakistan has connected to SEMEWE4 which provides Pakistan with a redundant link in case the outage occurs again.

PERN2 has planned to build Gigabit fiber network with a minimum of 1 Gbps for end nodes and a core of 10 Gbps. It is anticipated that about 90% of PERN2 nodes will have fiber connectivity. It will have 8 National level PoPs connected by leased dark fiber. Three metro ring 10 Gbps networks will be established in Islamabad/Rawalpindi, Karachi and Lahore. Seven local area PoPs will be established in these networks. It will serve > 300,000 students, faculty members and researchers. Initially 85 universities and institutes will be connected. In phase I Islamabad/Rawalpindi universities will be connected at 1 Gbps. The tender as been won by the Almoayed Group in January 2007 for the deployment of a 10Gbps Metro Ring in Islamabad for interconnecting 18 university campuses. Expected commencement of phase I is in September 2007. In phase II it will be extended to Lahore and Karachi. For the remaining five PoP cities the proposed topology is not a ring but spur only since there are very few universities initially targeted in the scope of the PERN II project. Service for phase II is expected to commence at the end of March 2008. Phase III will connect distant nodes. They will lease dark fiber and will also commence end March 2008.

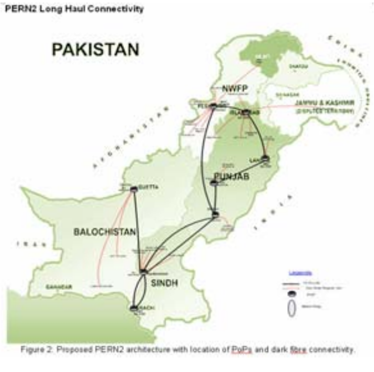

Figure 14 Proposed PERN2 Architecture

Mobilink has almost completed its backbone and has a submarine fiber link to its sister company TWA which will be the next national media provider after PTCL. This will be the third undersea fiber cable project for Pakistan. In February 2007 Telekom Malaysia announced that the company is set to complete its US$100 million countrywide fiber-optic-backbone project in Pakistan - the largest fiber-optic network in the country - by October 2007. The backbone will link more than 75 major towns and cities in Pakistan. The project is with Multinet, a Pakistan ISP that is now a subsidiary of Telekom Malaysia. A fourth company, Wateen is laying out a fiber backbone at a cost of $100M. It appears that all of this investment will provide more options for Pakistani network access.

In what is believed to be the largest WiMAX network of its kind, Motorola has been selected as primary supplier to Pakistan's Wateen Telecom, part of Warid Telecom "It also demonstrates how an emerging country can leapfrog directly to innovative next-generation technology, and smoothly deploy a cutting edge communications infrastructure".

In August 2006 NIIT[32] announced it that has 'made an entrance into high-performance computing by setting up the first grid enabled super computing facility in Pakistani academia[33]. As part of an ongoing collaborative research with CERN-Europe and SLAC-USA, the NIIT cluster will also act as a node for the computational and data Grid, spanning the globe to analyze data from particle physics experiments, solving highly complex matrices, simulate physical phenomena in electromagnetic, to model devices in quantum electronics and to analyze massive data sets in bioinformatics and seismology. The cluster will not only enable researchers to model and simulate computationally expensive experiments locally but will also facilitate them to run their jobs on internationally available grid enabled clusters across the world.

Sri Lanka

The Lanka Education And Research Network (LEARN)[31], started in 1990, is the NREN of Sri Lanka. LEARN is a member of APAN[34] and interconnects 24 sites in Sri Lanka with link speeds ranging from 128kbps to multiple 2Mbps links. The establishment of 2Mbps links to 8 sites with the financial support of Sida/SAREC has been a major milestone in this path. LEARN is currently in the process of upgrading the link bandwidths to 16 of its sites to 10Mbps over optical fiber. Several links have already been upgraded, and the remaining links will be upgraded by June 2007. This upgrade was made possible with the World Bank funded IRQUE Project providing funds for 10 of the 16 links.

HostSearcher[9] found 13 unique www hosts out of 182 discovered by Google in the (ac.lk) domain. All of these had RTT's < 400ms indicating that they have fiber connectivity.

Comparisons with Development Indices

(i) Comparison of TCP Throughput with Digital Access Index

In 2003, the ITU's[28] Market, Economics and Finance Unit launched the Digital Access Index (DAI) [27], a new index, which measures the overall ability of individuals in a country to access and use new Information and Communication Technology (ICT). The DAI is built around four fundamental vectors that impact a country's ability to access ICTs: infrastructure, affordability, knowledge and quality and actual usage of ICTs. The DAI has been calculated for approximately 180 economies where European countries were among the highest ranked. The DAI allows countries to see how they compare to peers and their relative strengths and weaknesses. The DAI also provides a transparent and globally measurable way of tracking progress towards improving access to ICTs. Most of the European countries lie above 1500 Kb/s throughput and greater than 0.6 DAI. With the exceptions being Malta, Belarus and Ukraine. Balkans is catching up with Europe with the exception being Albania which is way down.

Most of the East Asian countries lie in the same region of the scatter plot with the exception of China. Middle East and Russia are right in the middle. Two Middle Eastern countries Israel and Cyprus lie in the top cluster with Europe. The other exception in the Middle East is Iran which is way down.

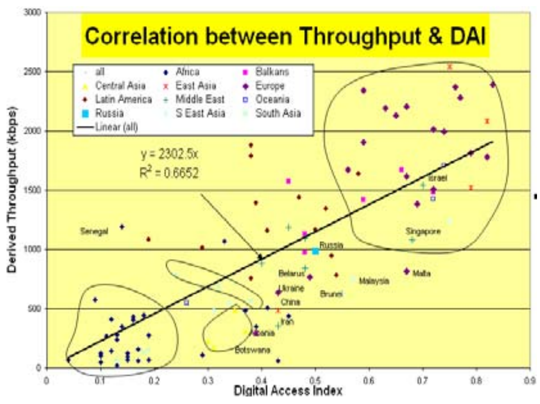

Figure 15 Correlation between Throughput & DAI

South East Asia can be divided into three categories with Singapore in the top, Malaysia and Brunei in the middle and Vietnam and Indonesia at the bottom. South Asia forms two clusters one is Pakistan, India and Sri Lanka which are reasonably good and the others Nepal, Bhutan etc which lies in the same category as Africa.

(ii) Comparison of TCP Throughput with the Network Readiness Index (NRI) 2006-2007

The Network Readiness Index (NRI) [29] comes from the The Global Information Technology Report 2006-2007 [30] of the World Economic Forum. NRI measures the degree of preparation of a nation or community to participate in and benefit from ICT developments. The NRI is composed of three component indexes which assess:
- environment for ICT offered by a country or community
- readiness of the community's key stakeholders (individuals, business and governments)
- usage of ICT among these stakeholders.

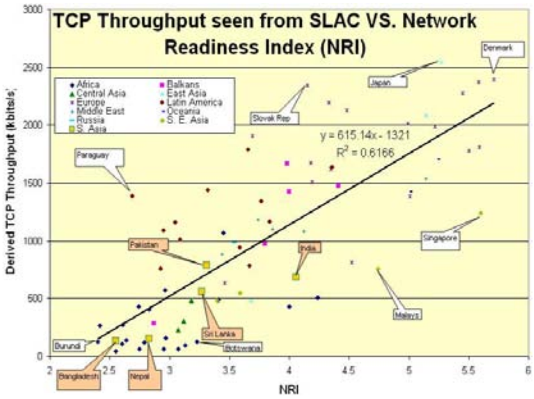

Figure 16 TCP Throughput as seen from SLAC VS Network Readiness Index (NRI)

There is a strong correlation (R^2>0.6) between the TCP throughput and NRI. Africa is mostly at the bottom with NRI less than 3.3 and TCP throughput mostly less than 1000 Kb/sec. Europe and East Asia are mostly at the top. In South Asia (highlighted) though India has the largest NRI it is between Pakistan and Sri Lanka in its TCP throughput

Conclusion

The growth of internet users from the year 2000 to 2007 has been about 220 % [3] and almost 900 % for South Asia, so the growth rate is very high. India and Pakistan are leading South Asian countries in terms of their network performance. Maldives, Sri Lanka and Bangladesh are following up. However Afghanistan, parts of Nepal, and parts of Bhutan are still connected through satellite.

The routes within South Asian Countries are very indirect. There is a need to build Internet Exchange Points within South Asian Countries so that they can communicate directly with each other. E.g building Internet Exchange points between India and Pakistan will be very useful for both countries.

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