Internet Performance Analysis of South Asian Countries using End-to-End Internet Performance Measurements

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Abstract—**Internet performance is highly correlated with key economic development metrics of a region. According to World Bank, the economic growth of a country increases 1.3% with a 10% increase in the speed of the Internet. Therefore, it is necessary to monitor and understand the performance of the Internet links in the region. It helps to figure out the infrastructural inefficiencies, poor resource allocation, and routing issues in the region. Moreover, it provides healthy suggestions for future upgrades. Therefore, the objective of this paper is to understand the Internet performance and routing infrastructure of South Asian countries in comparison to the developed world and neighboring countries using end-to-end Internet performance measurements. The South Asian countries comprise nearly 32% of the Internet users in Asia and nearly 16% of the world. The Internet performance metrics in the region are collected through the PingER framework. The framework is developed by the SLAC National Accelerator Laboratory, USA and is running for the last 20 years. PingER has 16 monitoring nodes in the region, and in the last year PingER monitors about 40 sites in South Asia using the ubiquitous ping facility. The collected data is used to estimate the key Internet performance metrics of South Asian countries. The performance metrics are compared with the neighboring countries and the developed world. Particularly, the TCP throughput of the countries is also correlated with different development indices. Further, worldwide Internet connectivity and routing patterns of the countries are investigated to figure out the inconsistencies in the region. The performance analysis revealed that the South Asia region is 7-10 years behind the developed regions of North America (USA and Canada), Europe, and East Asia.**

Index Terms—**Internet performance monitoring, PingER, packet loss, ping, round trip time**

1. Introduction

The Internet is rapidly transforming social, cultural, economic and political aspects of life. This increases the number of Internet users and the development of numerous Internet applications for businesses, education, entertainment, news, gaming and social networking. Consequently, Internet traffic is increasing tremendously day by day. Moreover, all these applications require a rigorous amount of end-to-end link performance in terms of scalability, reliability, and performance. A delay of few hundred milliseconds can cost millions of dollars to the businesses. For example, the study by Singla et. al. [1] shows that: a 100 ms delay causes `Amazon` a loss of 1% of sales; a 400 ms delay in search responses decreases the search volume of `Google` by 0.74%; and a 500 ms of delay in Internet performance reduces the revenue of `Bing` by 1.2% per user. Similarly, the study shows that most of the consumers abandon the web site if they have to wait for more than 3 seconds to load a page. As a result, the user experience is impaired and revenue is reduced for the service providers.

The Internet performance is also directly tied to key economic development metrics of the countries. According to the World Bank, the economic growth of a country increases 1.3% with a 10% increase in the speed of the Internet [2]. In terms of Internet performance, the countries in regions such as South Asia, Central Asia, and Latin America are 5-9 years behind countries in the regions such as North America, Europe, and East Asia. African countries are nearly 15 years behind Europe in terms of Internet speed. Similarly, only 28.3% of the African people have the Internet access as compared to 76.7% of Europeans and 89% of North Americans [3], [4], [5]. The same relationship holds when we correlate these countries in terms of their economic development. Thus, Internet performance participates effectively in the economic development of the countries and the regions.

South Asia is one of the highly populated and fast-growing regions of the developing world. According to the UN[1], it has a population of 1.749 billion that is one-fourth of the world's population. It includes Afghanistan (34 million), Bangladesh (164 million), Bhutan (0.79 million), India (1.3 billion), Maldives (0.37 million), Nepal (29 million), Pak-

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1. http://www.un.org/

This material is based upon work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-76SF00515.

TABLE 1: Internet user statistics in South Asia dated March 31, 2017

Asia	Population	Internet Users in year 2000	Internet Users in March 2017	Penetration rate (% Population)	Percent Growth rate (2000-2017)
Afghanistan	34,169,169	1,000	4,005,414	11.7	298.5
Bangladesh	164,827,718	100,000	66,965,000	40.6	195.78
Bhutan	792,877	500	295,177	37.2	189.64
India	1,342,512,706	5,000,000	462,124,989	34.4	112.63
Maldives	375,867	6,000	270,000	71.8	88.6
Nepal	29,187,037	50,000	6,400,000	21.9	124.49
Pakistan	196,744,376	133,900	35,835,400	18.2	153.86
Sri Lanka	20,905,335	121,500	6,614,164	31.6	94.68

istan (196 million), and Sri Lanka (21 million)[2]. Among them, India is the largest and fastest growing economy and includes a population of over 1.3 billion people. However, only 34% of the population is connected to the Internet. On the other hand, China with a population of 1.38 billion, 52% of the population are using the Internet. Similarly, Afghanistan has the lowest number of the Internet users in the region i.e., 11.7% of the population. It is an interesting fact that in the year 2000, there were only 1000 Internet users in Afghanistan. This grew to 4 Million in March 2017 with a growth rate of about 300%. The Internet user statistics of the South Asian countries are summarized in Table 1[3].

The objective of this paper is to understand the Internet performance and routing infrastructure of South Asian countries in comparison to the developed world and neighboring countries using end-to-end Internet performance measurements. The data for the analysis and comparison is collected through the PingER framework. This is a well-known Internet performance monitoring framework developed by the SLAC National Accelerator Laboratory[4], USA and is running for the last 20 years. The framework uses the ubiquitous `ping` facility to capture the performance of the Internet links. The detailed discussion on the PingER framework and methodology is available in Sections 2 & 3. The captured ping statistics are used to calculate key Internet performance metrics for the Internet links of South Asian countries. These performance metrics reveal interesting information when compared with the developed world and among neighboring countries. Further, in this paper, the derived TCP throughput of the countries in the South Asia region is compared with the development indices available from the UN and the International Telecommunications Union (ITU)[5]. The comparison will help to determine the strength of the correlation between the Internet Performance metrics and development indices in the South Asia region.

The remaining paper is organized as follows. Related work is discussed in Section 2. Section 3 provides the performance monitoring methodology. PingER coverage in South Asia is explained in Section 4. Internet connectivity and routing in South Asian countries is described in Section 5 and Section 6, respectively. Performance analysis of South Asia region is presented in Section 7, and finally, Section 8 concludes the paper.

2. Related work

The active Internet performance monitoring of a region is essential to understanding the current performance of the links. It helps to figure out the infrastructural inefficiencies, poor resource allocation, and routing issues in the region [6]. A number of Internet performance monitoring frameworks are available e.g., SamKnows[6], BISmark [7], Dasu [8], Netradar [9], Portolan [10], RIPE Atlas [11], and perfSONAR [12] originally partially based on the PingER framework [13]. In-depth reviews of these Internet performance frameworks based on their deployment methodology, probing technique, features, and research impacts are available in the literature [14], [15], [16], [17]. Mostly, these platforms use `ping`, `mtr`, `cron`, `ntp`, `dig`, `netstat`, `iperf`, and `traceroute` commands to monitor the Internet performance of the links in terms of loss, round trip time, throughput, routing etc. The data collected by these platforms is used to analyze the end-to-end performance of the links, quantifying the digital divide among the regions, detecting congested routes, identifying last mile problems and evaluating the impact of major events i.e., cable cuts, tsunamis, earthquakes, and social upheavals.

PingER (Ping End-to-end Reporting)[7] is an Internet End-to-end Performance Measurement (IEPM)[8] framework led by the SLAC National Accelerator Laboratory. It is active since 1998 and contains a multi-domain historical dataset from 700 nodes in 170 countries of the world. It covers an area containing 98% of the Internet population of the world [2]. Basically, it was designed to monitor the end-to-end performance of the Internet links for modern High Energy Nuclear and Particle (HENP) physics experiments taking place among SLAC, the Brookhaven National Laboratory (BNL)[9] and the European Center for Particle Physics (CERN)[10] [13]. However, since the last decade, the objective of the project is to monitor the end-to-end performance of the Internet links world-wide. PingER is actively monitoring the performance of the Internet links in the South Asia

2. https://esa.un.org/unpd/wpp/
3. http://www.internetworldstats.com/stats.htm
4. https://www6.slac.stanford.edu/
5. http://www.itu.int/en/Pages/default.aspx
6. https://www.samknows.com/
7. www-iepm.slac.stanford.edu/pinger/
8. http://www-iepm.slac.stanford.edu/
9. https://www.bnl.gov/world/
10. http://home.cern/

region since 2000. Therefore, it is used in this paper to monitor, analyze and compare the performance of the links in South Asian countries with the developed regions.

3. Performance Monitoring Methodology

The PingER framework consists of three types of hosts i.e., monitoring hosts, remote hosts, and archive hosts. A monitoring host is a computer (with minimal hardware specification) where the PingER Monitoring Agent (MA) software is installed. Currently, there are 50 installations of PingER MAs in 23 countries of the world. Each MA deploys the ubiquitous ping facility to check and monitor the performance of the Internet links. Remote hosts are normally the web servers of the organizations with stable uptime and are monitored by the MAs at regular intervals. There is no software requirement for the remote host except that it must be pingable from the MA. Currently, there are 50 MAs which monitor nearly 700 remote hosts in 170 countries of the world [18]. Thus, there are 10,000 MA-remote host pairs worldwide monitoring the performance of Internet links. The measurement cycle is activated at each MA every thirty minutes by sending a set of 100-byte ping requests and 1000-byte ping requests to a list of target remote hosts. The maximum number of pings in each set are fixed to thirty. However, the MA stops sending pings when it receives 10 ping responses or the total number of ping requests reaches 30. The raw data recorded for each set of pings contains: the names and IP addresses of the MA & target remote site along with the timestamp, packet size, minimum, average and maximum Round Trip Time (RTT) values of the ping responses and the individual ping RTTs and their sequence numbers. Afterwards, the Archive host, which is a central storage repository at SLAC, fetches all the raw data collected by each MA on daily basis. At present, the volume of the compressed dataset is about 60 Gigabytes and is comprises of over 100,000 flat files [19]. The data is processed to extract sixteen key performance metrics including: packet loss, minimum, maximum & average RTT, TCP throughput, Mean Opinion Score (MOS), jitter, directness of connection and reachability. The raw data can be downloaded via anonymous FTP[11], while long-term reports are publicly available through a web interface[12].

4. Pinger Coverage in South Asia

South Asian countries comprise nearly 32% of the Internet users in Asia and nearly 16% of the world. Major contributors are India, Bangladesh, Pakistan and Sri Lanka. The coverage map of PingER hosts in South Asian countries is shown in Figure 1. PingER MAs are shown as red dots and remote hosts are shown as green. Blue dots are beacon sites which are monitored by most of the MAs in the world. At present, PingER has 16 MAs in the region. It includes one in India (Amity University, Noida, Uttar Pradesh), one in Bangladesh (Daffodil International University, Dhanmondi, Dhaka) and 14 in Pakistan (Allama Iqbal Open University, Islamabad, University of Agriculture, Peshawar, NUST-CAE PAF Academy Risalpur, COMSATS Sahiwal, ISRA Hyderabad, Kinnaird College for Women Lahore, KUST Kohat, Namal College Mianwali, Quaid-e-Azam University Islamabad, NU-FAST Karachi, UET Peshawar and the remainder are in the NUST Islamabad). Further, in the last year PingER monitors about 40 sites in the region, 2 in Afghanistan, 9 in Bangladesh, 2 in Bhutan, 2 in India, 4 in Sri Lanka, 5 in Maldives, 5 in Nepal and 11 are in Pakistan. The distribution of PingER hosts in South Asia is summarized in Table 2.

Figure 1: Locations of PingER MAs, beacons, and remote sites in South Asia as of July 2017

TABLE 2: Distribution of PingER hosts in South Asia

Country	Monitoring Agents (MAs)	Beacons	Remote sites
Afghanistan	0	1	2
Bangladesh	1	2	9
Bhutan	0	0	2
India	1	2	2
Maldives	0	0	5
Nepal	0	1	5
Pakistan	14	2	11
Sri Lanka	0	1	4
Total	16	9	40

11. ftp://ftp.slac.stanford.edu/users/cottrell/
12. http://www-wanmon.slac.stanford.edu/cgi-wrap/pingtable.pl

TABLE 3: Submarine cables in South Asia

Country	Cities	Submarine cable
Bangladesh	Cox's Bazar	SeaMeWe-4
	Kuakata	SeaMeWe-5
India	Chennai	Bay of Bengal Gateway, SeaMeWe-4, Tata TGN-Tata Indicom, i2i Cable Network
	Cochin	SAFE, SeaMeWe-3
	Puducherry	IOX Cable System
	Trivendrum	WARF Submarine Cable
	Tuticorine	Bharat Lanka Cable System
	Mumbai	Africa-1, Asia Africa Europe-1, Bay of Bengal Gateway, SeaMeWe-3, SeaMeWe-4, Europe India Gateway, FALCON,,FLAG Europe-Asia, Gulf Bridge International Cable System/Middle East North Africa Cable System, IMEWE, SEACOM/Tata TGN-Eurasia
Maldives	Dhangethi, Fuvahmulah, Gahdhoo, Gan	Dhiraagu Cable Network
	Eydhafushi, Hithadhoo,	Dhiraagu Cable Network,
	Hulhumale,Kulhudhufushi	Nationwide Submarine Cable Ooredoo Maldives
	Kolhufushi, Thinadhoo	Nationwide Submarine Cable Ooredoo Maldives
	Male	Nationwide Submarine Cable Ooredoo Maldives, WARF Submarine Cable
Pakistan	Gwadar	Silk Route Gateway (SRG-1)
	Karachi	Africa-1, Silk Route Gateway (SRG-1), Asia Africa Europe-1 (AAE-1), SeaMeWe-3, SeaMeWe-4, SeaMeWe-5, Transworld (TW1), IMEWE
Sri Lanka	Colombo	Dhiraagu-SLT Submarine Cable Network, SeaMeWe-4, WARF Submarine Cable
	Matara	SeaMeWe-5
	Mt. Lavinia	Bharat Lanka Cable System, SeaMeWe-3
	Ratmalana	Bay of Bengal Gateway (BBG)

5. Internet Connectivity in South Asian Countries

The countries like India, Pakistan, Bangladesh, Sri Lanka and Maldives are directly connected through submarine cables as shown in Table 3. Afghanistan is connected to all its neighbors including Pakistan, Turkmenistan, Tajikistan, Uzbekistan Iran via terrestrial fiber cables, except for China. However, it does not have a central gateway in the country. Bhutan and Nepal are optically connected to the world through India. Hopefully, in September 2017, Nepal will also get an optical fiber connection from China. Besides the commodity Internet, the Trans-Eurasia Information Network (TEIN) which is one of the largest education and research network, plays a key role by providing the high-capacity Internet services dedicated to educational institutions and research centers across the South Asian countries. Further, it provides a dedicated connectivity to the European universities and research centers served by the GÉANT network. The Pakistan Education and Research Network (PERN) was the first in South Asia connected to 155 Mbps link to TEIN3 in Singapore in late 2008. Later a TEIN3 PoP was established in Mumbai with the cooperation of the National Research and Education Network (ERNET) of India. As a result, the 2.5 Gbps links between Mumbai and Europe (GEANT Madrid PoP), and Mumbai and TEIN3 Singapore PoP became operational in February 2010. Initially, ERNET was connected to TEIN3 with 1 Gigabit Ethernet connection on March 8, 2010 and was increased to 10 Gigabit Ethernet interface after a short period of time. The Nepal Research and Education Network (NREN) was connected on March 24, 2010 at 45 Mbps whereas the National Research and Education Network of Sri Lank was connected on April 1, 2010 at 45 Mbps. Similarly, the Bangladesh Research and Education Network (BdREN) achieved online boost through a high-speed connection to the TEIN3 in 2012. Thus, both the commodity Internet and the global educational & research network connectivity transformed the Internet penetration in the South Asian region.

TABLE 4: Latency from Pakistan to USA, Europe and South Asian countries

Source	Target	Latency (ms)
Pakistan	USA	337
	Europe	302
	Afghanistan	292
	Bangladesh	453
	Bhutan	220
	India	470
	Maldives	271
	Nepal	368
	Sri Lanka	157

6. Routing in South Asian Countries

With the help of the PingER traceroute server at the National University of Sciences and Technology (NUST), the traceroute results from Pakistan to the South Asian countries, Europe and USA are shown in Figure 2. Pakistan has a direct connectivity to Europe with a latency of 302 ms. Similarly, the traffic to the USA also routes directly through Europe with a latency of 337 ms as shown in Table 4. However, Pakistan has an indirect connectivity with all its neighboring countries except for Sri Lanka in the South Asian region. In the case of India, Afghanistan, Maldives, and Nepal the traffic is routed through Europe. Most

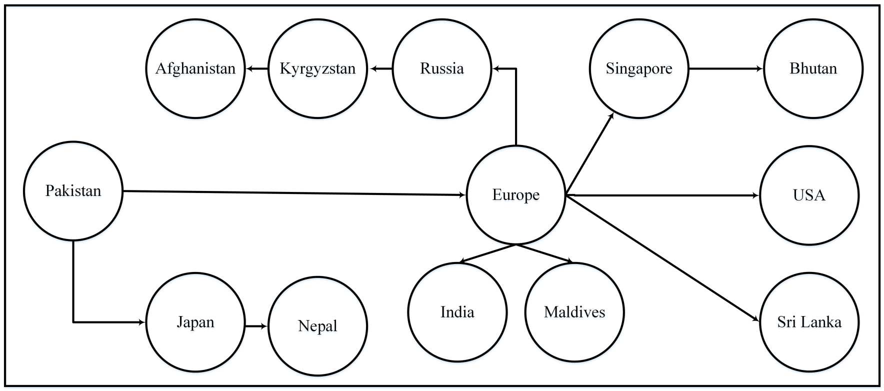

Figure 2: Routes to USA, Europe and South Asian countries as seen from Pakistan

important, the main link that connects Kabul, Afghanistan to other regions of the world is via Moscow, Russia as shown in Figure 2. For Bhutan, traffic is routed through Singapore. Similarly, the connectivity between Pakistan and Bangladesh is very indirect as it goes via Europe. The latency from Pakistan to USA, Europe, and neighboring countries is summarized in Table 4. The major reason for the high values of latency is due to the indirect routes between the countries in the region. This concludes that the direct links with neighboring countries need to be established for faster connectivity in the region.

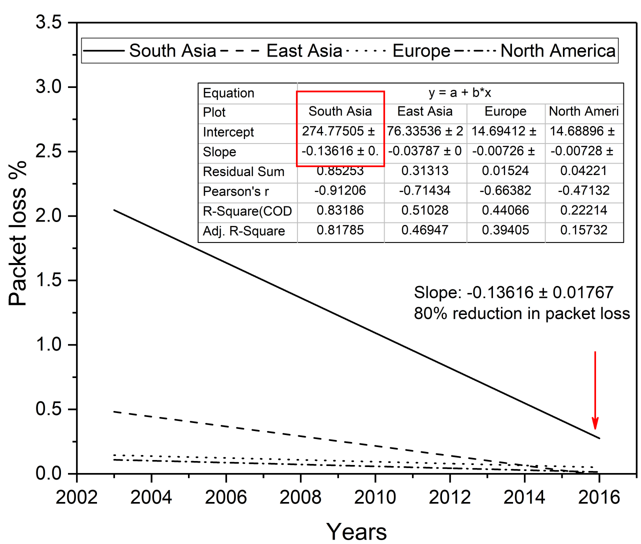

Figure 3: Worldwide yearly packet loss as seen from SLAC, USA

7. Performance Analysis

In this section, the Internet performance of the South Asian countries is compared with the developed world in terms of losses, minimum RRT, reachability, MOS, and TCP throughput. Further, the TCP throughput is also correlated with development indices of the world.

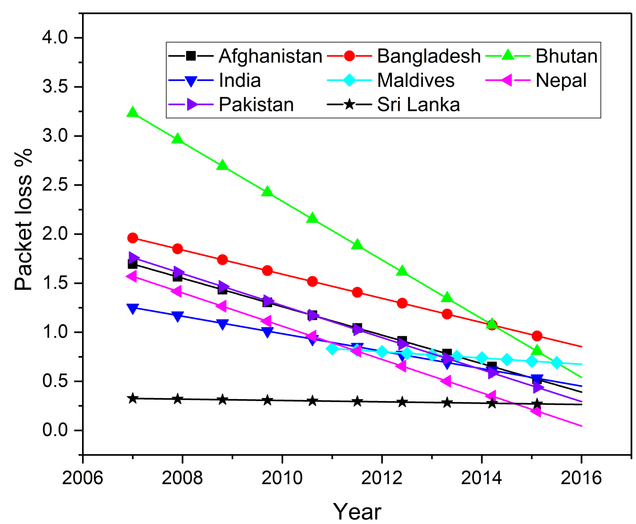

Figure 4: Packet loss as seen from SLAC, USA to South Asian countries

7.1. Losses

The quality of the Internet is highly associated with the packet loss. The packet loss is normally caused by congestion, queuing buffer overflow, bottleneck links, faulty network hardware or drivers, noisy or faulty connectors and sometimes due to the delivery of an imperfect copy of the packet. The packet loss directly affects the throughput of the network. Especially, it affects the user experience in case of media streaming services and online games. Particularly for TCP based application, it causes the increase in latency due to the extra time needed for retransmissions of the packets. The quality threshold levels defined by PingER for packet loss are: 0-0.1% excellent, 0.1-1% = good, 1-2.5% = acceptable, 2.5-5% = poor, 5-12% = very poor, and greater than 12% = bad. The packet loss from SLAC, USA to South Asia, East Asia, Europe and North America is shown in Figure 3. As the packet loss is independent of the distance between the source and the destination, therefore, there is no need to normalize the data. It is clear from the

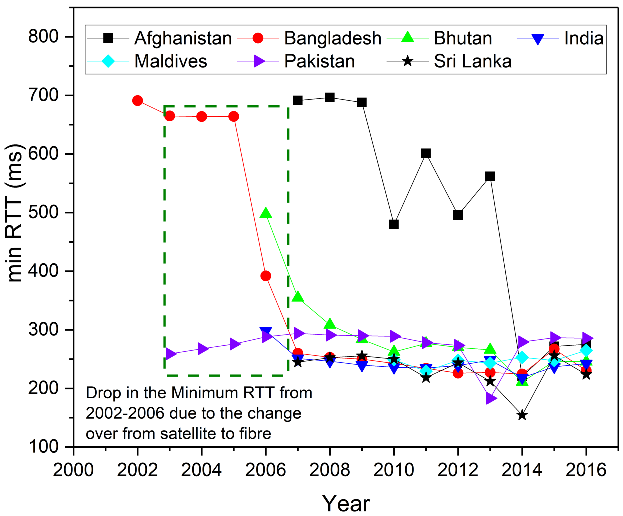

Figure 5: Minimum RTT as seen from SLAC, USA to South Asian countries

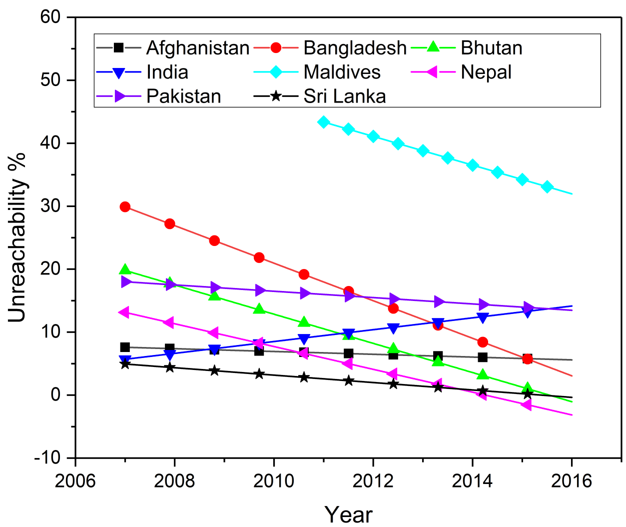

Figure 6: Unreachability % of South Asian countries as seen from SLAC, USA

figure that the South Asia suffers from high packet loss (i.e., greater than 0.5%) as compared to developed regions of the world (i.e., North America, Europe and East Asia) having losses below 0.1%. However, the South Asia has shown a significant improvement with the drop-in packet loss to 80% as compared to the year 2003. Among the South Asian countries when measured from SLAC on yearly basis, Bangladesh and Maldives suffer from the highest losses due to edge effect whereas the lowest packet losses are observed by Nepal as shown by the linear fits in Figure 4.

7.2. Minimum RTT

The minimum RTT observed from SLAC to South Asian countries is shown in Figure 5. The huge drop in min RTT

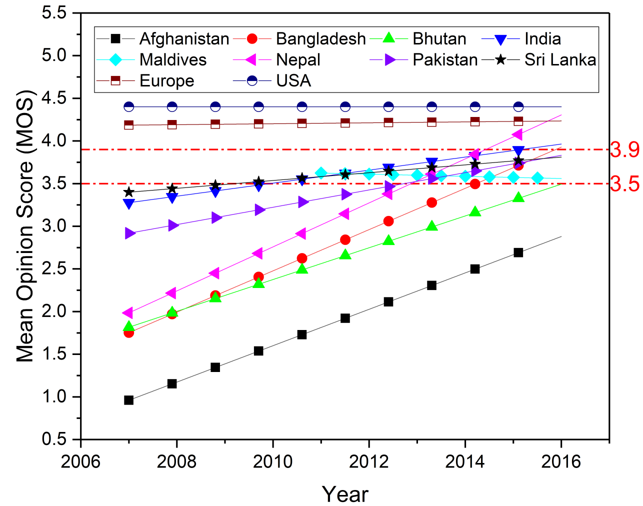

Figure 7: Mean Opinion Score of South Asian countries as seen from SLAC, USA

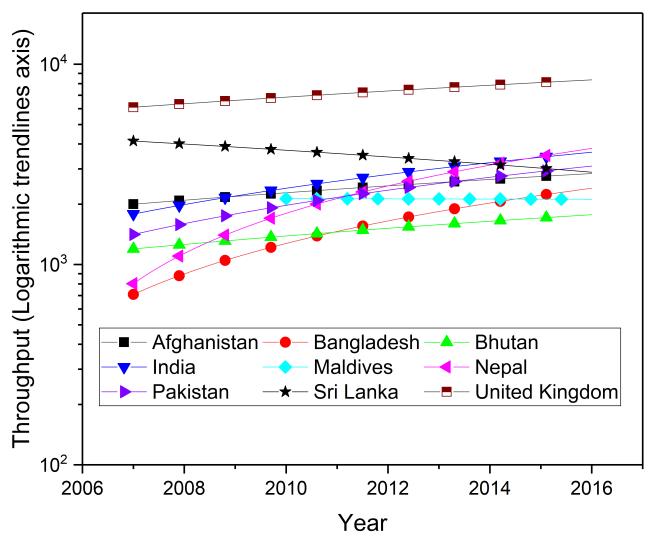

Figure 8: TCP Throughput of South Asian countries and Europe as seen from SLAC, USA

is clearly visible from the year 2003 to 2006. This is due to the change over from satellite links to fiber optics except for Afghanistan which took place around 2010. Further, the minimum RTT values in the year 2016 are less than 300 ms which indicates that all the countries are reachable through terrestrial routes. However, the minimum RTT value is quite high when we compare the values within the South Asian region. This is because the routes between the neighboring countries are very indirect. In most of the case, it goes via Europe, Singapore, and Hong Kong. As a result, the values of the minimum RTT become high.

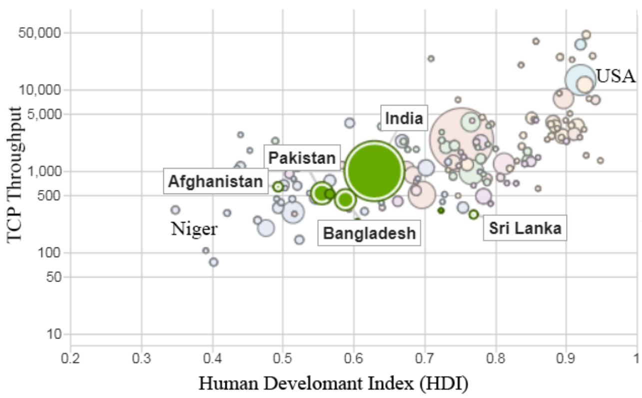

Figure 9: Human Development Index (HDI) & South Asian countries

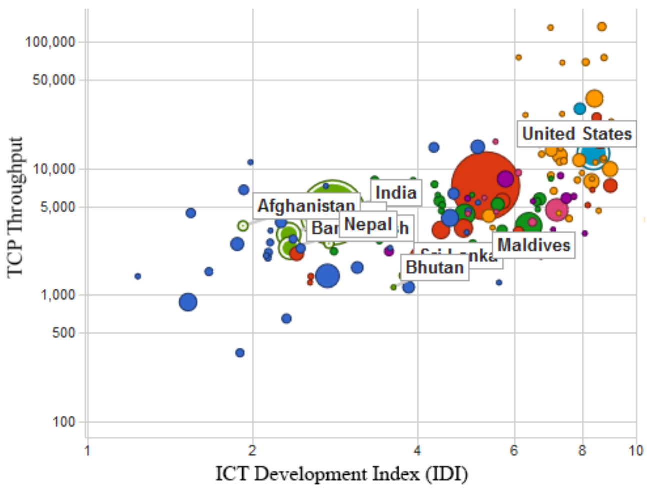

Figure 10: ICT Development Index (IDI) & South Asian countries

7.3. Reachability

The reachability is also calculated using the ping statistics. The monitoring host ping's each target host or site by 21 times with an interval of 30 minutes. The host is marked as unreachable if all these pings fail to respond. This metric predicts the fragility of the links and helps to find out the last mile problem in the network. Figure 6 shows the unreachability % of South Asian countries when seen from SLAC. The Bangladesh has shown a significant improvement as cumulative unreachability is reduced from 30% to 4%. Similarly, in the case of Bhutan, it was reduced from 20% to 1%. Nepal has the lowest unreachability, however, Maldives has the worst values.

7.4. Mean Opinion Score

The Mean Opinion Score (MOS) is used as a voice quality metric in the telecommunication industry. It is a function of latency, jitter and packet loss. Normally, the values range on a scale from 1 (for bad) to 5 (for excellent). The standard range for VoIP service is 3.5 to 4.2. However, for a perfect connection, the maximum achievable MOS value ranges from 4.2 to 4.4 due to the impact of the compression algorithms of the codecs. Figure 7 shows the MOS values of the South Asian region as seen from the SLAC, USA. All the countries barely touch the lower limit of the MOS making overall VoIP service marginal in the region. India is on the top with the maximum value of 3.9, however, still lagging Europe and USA. The increase in the values during the period of 2007 to 2010 are due to their transformation towards the fiber links in the region. Afghanistan switched from satellite connectivity to terrestrial fiber links during 2010. Thus, VoIP services improved to a satisfactory level in the region.

7.5. TCP Throughput

Figure 8 shows the normalized TCP throughput of South Asian countries and Europe as seen from SLAC, USA. The throughput is calculated using Mathis formula which says that the TCP throughput is inversely proportional to the RTT and square root of the loss [20]. The RTT measured from SLAC to the US is much shorter than to the rest of the world. Hence the throughput for the US is larger. Thus, USA is not included in the comparison. The lines show that South Asian countries are 7-10 years behind Europe. Bhutan has the worst throughput as seen from SALC. However, it will improve in near feature as it will get a terrestrial fiber connectivity from China.

7.6. Development Index & South Asian Countries

The Human Development Index (HDI)[13] is composed of life expectancy, knowledge (measured by literacy rate), and GDP per capita indicators to categories the countries into four different tiers of human development. The developing countries mostly have International Internet traffic. Therefore, a high-performance Internet infrastructure always contributes towards education and economy of these country. In Figure 9, the derived TCP throughput of the South Asian countries is correlated with the HDI index. As expected, South Asian countries are lagging the developed world (i.e. USA > 0.9). Further, Maldives and Sri Lanka are showing good development as compared to highly populated India, Pakistan and Bangladesh. Afghanistan, Bhutan and Nepal are closer towards African countries with low HDI values. Similarly, the ICT Development Index (IDI) [21] is developed by United Nations International Telecommunication Union to quantify the digital divide in the world. Further, it is used to compare the ICT performance metrics within the countries based on the access, use and skills of ICT technologies. In Figure 10, again South Asian countries show moderate values of throughput and IDI index as compared to the developed world.

13. http://hdr.undp.org/en/content/human-development-report-2010

8. Conclusion

South Asia is a highly populated and fast-growing region of the developing world. Nearly 32% of the population of the region is connected to the Internet with a growth percentage improvement of 160% as compared to the year 2000. India, Pakistan and Bangladesh have shown significant improvement in terms of international connectivity, infrastructure and performance. As a result, latency is reduced and overall throughput of the countries is increased. Although, Afghanistan is lagging all the countries in the region, however, its Internet user growth rate is increased to 300% as compared to the year 2000. Nepal, Bhutan and Sri Lanka have shown a moderate improvement in terms of packet loss, throughput and MOS values. Overall, the region is 7-10 years behind Europe and East Asia regarding the Internet performance, however, it is quite ahead of Africa. Similar trends occur among the countries when HDI and IDI are correlated with derived throughput of the countries. Further, the routing is quite indirect in this region. For most of the neighboring countries, the traffic is routed through Europe, Singapore, Hong Kong, and Russia (in case of Afghanistan). As a result, minimum RTT values become high in the region. Thus, the countries have a moderate MOS score which is used to measure the voice quality. All the above valuable findings are made using historical end-to-end Internet performance measurements carried out by the PingER framework in the region. These outcomes can be used to upgrade the capacity and performance of the Internet links in the region.

Acknowledgments

This material is partially based upon work supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics, under Contract DE-AC02-76SF00515. Further, this work is supported in part by the National Natural Science Foundation of China under Grants 61632009 & 61472451, in part by the Guangdong Provincial Natural Science Foundation under Grant 2017A030308006 and High-Level Talents Program of Higher Education in Guangdong Province under Grant 2016ZJ01.

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