Measuring Broadband Access Network Performance in Pakistan: A Comparative Study

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Abstract—**Although broadband Internet relishes wide penetration in Pakistan, performance of fixed and wireless broadband networks have not been thoroughly investigated from perspective of end-users. To the best of our knowledge, no independent study exists to date documenting home user broadband experience in Pakistan. This dearth of information is troubling as benchmarking broadband performance is fundamentally important for consumers in Pakistan due to its big Internet market. To address this gap, we conducted a pilot study of both fixed landline and fixed wireless broadband connections in Pakistan through deployment of programmable wireless routers for home users. Our work is inspired by (and compares to) a previous study of fixed and wireless broadband performance in South Africa that was published in 2013, drawing comparisons to previous work where appropriate. We measure the performance of both fixed landline and fixed wireless ISPs. Our findings agree with the findings of this previous work, suggesting that (1) consumers in Pakistan are not getting advertised speeds; (2) wireless broadband satisfies the advertised performance bounds better than wired broadband in a majority of cases under consideration; (3) network latency often contributes to performance bottlenecks more than throughput; and (4) ISPs in Pakistan shapes internet traffic in order to bring in compliance with desired traffic shape. Limiting factors such as latency mean that investing in local server infrastructure and rich peering between different ISPs will also make a significant difference in improving the Internet experience for users in Pakistan.**

I. Introduction

As the Internet becomes an integral part of people's lives, a community of researchers has focused their efforts to improve the performance of fixed and wireless broadband access. Fixed and wireless broadband access is proliferating around the world, and Pakistan is no exception. Despite the proliferation of broadband connectivity in the country, little is known about the performance of these networks. In particular, fixed and wireless broadband subscribers have little information about the performance of these networks within the country.

Our previous work has studied the performance of fixed and wireless broadband access networks in both developed countries (i.e., the United States) and, by contrast developing regions (i.e., South Africa). This previous work has illustrated some of the stark differences between connectivity in developed countries and those of less developed regions. In particular, our study of fixed and wireless broadband performance in South Africa highlighted the fact that many fixed and wireless providers do not achieve advertised rates, that wireless generally provides higher, but more variable throughput than fixed-line, that latencies to certain destinations and geographic regions can be high due to sparse peering, and that connectivity is not robust to failures. Our goal in this study is to re-examine some of the questions from these previous studies in the context of broadband service providers in Pakistan.

Today, in Pakistan, neither broadband users nor regulatory authorities have access to measurements of broadband access networks from the perspective of home users. Better data is needed to help inform users about value for money [1]; furthermore, when performance does not meet standards, broadband usage declines [2], [3] resulting in and accompanying the decline of country's development indicators [4]. Our main objective is thus to evaluate the quality of broadband connectivity in Pakistan, using previous similar studies as a guide and baseline for comparison. In addition to providing a better picture of connectivity from a previously unexplored region of the Internet, the data we collect, which is all publicly available [1], can help better inform investment and policy-making in this region [5]–[7]. This paper tackles the following questions:

- Do fixed and wireless broadband subscribers in Pakistan achieve the speeds that their ISPs advertise?
- How consistent is the performance that these users experience over time?
- How do factors such as latency contribute to the end-to-end performance that user experience in Pakistan?

The rest of the paper is structured as follows. In Section 2, we discuss the background of our study and present metrics and methods used for measuring broadband performance. We present our approach for measuring broadband performance compared with alternative approaches. Section 3 presents the results of our ongoing study aiming to benchmark ISPs (fixed land line and fixed wireless) across Pakistan. Section 4 discusses and concludes the broader implications of our results.

[1] http://uploads.projectbismark.net/

II. Background and Method

We provide a brief background of Internet access in Pakistan and describe our measurements in detail.

A. Broadband in Pakistan

Table I provides a few facts about the current state of Internet access in Pakistan [8]. In short, Pakistan is on the fast lane in terms of broadband Internet. We consider Broadband both in terms of broadband technology and higher data rates. There are nearly 30 million Internet users with penetration rate of 16% [9]. There are almost 50 Internet service providers [9] and the number of customers using broadband is nearly 2.2 Million [10]. The growth rate of users is the second highest in South Asian Association for Regional Cooperation (SAARC) countries in accordance with its population [10]. Broadband in Pakistan includes fixed line via Digital Subscriber line (DSL), Fiber to the Home (FTTH), 3G USB modem and WiMax (IEEE802.16d) connections. Figure 1 shows penetration rate of the corresponding technologies [11]. According to Pakistan Telecommunication Authority (PTA) annual report 2013-14, 70.9 % of internet market share is hold by PTCL [11]. Similarly 10.3% by Wateen, 7.3 % by WiTribe, 2.7 % by Qubee and rest is shared among others. Table II shows the service plan rates of deployments, average/median pay in Pakistan along with cost of broadband in Pakistan.

Unfortunately, regulatory policy has not kept up with the evolution of Internet access in Pakistan. An initial broadband policy was drafted in December 2004 [12]. After 2004, number of ISPs came into existence and broadband access increased in popularity. However, there have been no updates to policy since; for instance, it does not address how the quality of broadband is to be monitored and regulated. We hope that our study will help authorities to draft new policies for monitoring and regulating broadband ISPs.

Internet users (estimated)	30 Million
Mobile Internet users	15 Million
Broadband Internet Connections	1.7 Million (DSL, WiMax, HFC & Evo
Cost of 2 Mbits IP backbone connection	US$ 400 per month
Internet bandwidth to Pakistan	400 Gbps combined from PTCL and TWA submarine cables
Operational ISPs	50 (approx)
Undersea cables connecting Pakistan to rest of world	Three with PTCL , SMW3, SMW4 & IMEWE One with TWA
Domestic Fiber backbones	PTCL, Wateen, Multinet, Mobilink
Fiber to the Home (FTTH) Provider	Nayatel
Domains Registered under .pk domain	30,000

TABLE I: Fast Internet Facts about Pakistan [8]

B. Measurement Method & Approaches

We aim to benchmark the Internet service providers in Pakistan directly from users home gateway. A number of methods and techniques are used in order to measure broadband

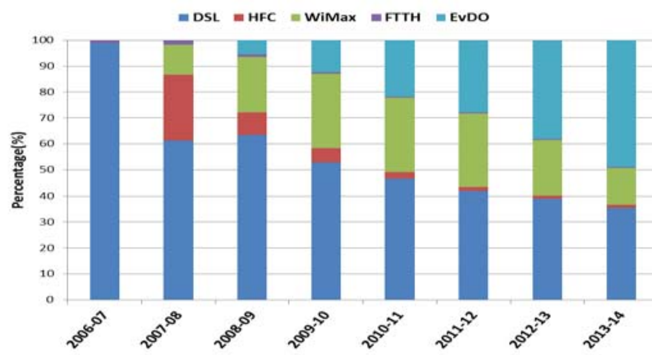

Fig. 1: Year wise penetration rate of various technologies in Pakistan [11]

performance. One method is taking measurements from the end host. Such types of measurements are called host-based measurements. These types of measurements can be done by asking user to download a specific application [14] on an end machine and then running web application measures speed tests for upload and download throughput along with latency. One prominent web application is speedtest.net by Ookla [15]. There are also other content distribution services for performing host based speed tests like Akamai. Host based measurements are affected by certain limitations. These limitations include factors such as the home network environment like home wireless network, limitations of the end host and interference from multiple users accessing the same uplink. The measurements depend on users to execute it and only represent snapshots of the network at the specific time at which the measurement was taken [16]. Such types of measurements vary continuously and cannot provide exact or accurate measurements. These measurements may be inconsistent with actual performance over time [5].

In contrast to host-based measurements, another approach measures directly from the home router. In router based measurements, a router equipped with special firmware is distributed among users in order to measure broadband performance. Users are asked to replace their default router with the custom router or connect it along with default router. The advantage of such types of measurement is that the router is always on and connected to the line resulting in continuous measurements without any interference from a user. These tests produce cleaner and more accurate measurements since home factors influencing measurements are accounted for [17]. The main disadvantage of such type of measurements in developing countries like Pakistan is that router tools are expensive and difficult to buy and deploy. For the purposes of this study, we deployed router hardware on loan from the United States in home networks in Pakistan to perform our measurements.

C. Deployment Scenario

We deployed 15 programmable OpenWrt routers running the BISmark firmware among users with different ISPs

ISP	Service Rates of Deployments (Users 1,2,3 and onwards)	Technology	Data Rate (Mbps)	Cost (PKR)/Month	
				Capped	Unlimited
PTCL	2 Mbps, 2 Mbps, 2 Mbps, 1 Mbps,2 Mbps	ADSL +	1	499 (10GB)	1250
			2	750 (10GB)	1549
WiTribe	0.5 Mbps, 1 Mbps	WiMax 802.16d	1	1099 (12GB)	1399
			2	NA	1999
Wateen	2 Mbps, 1 Mbps	WiMax 802.16d	1	900 (10GB)	1399
			2	1499 (20GB)	2999
Qubee	1 Mbps	WiMax 802.16d	1	1000 (20GB)	1400
			2	1200 (20GB)	1700
Nayatel	3 Mbps, 5 Mbps	FTTH	3	1899 (30GB)	NA
			5	2999 (30GB)	NA

TABLE II: Service plan rates and generalized tariff of broadband ISP's in Pakistan. Average/median pay in Pakistan for fiscal year June 2013-July 2014 was USD 1,307 per year (PKR 11,000/Month) [13]

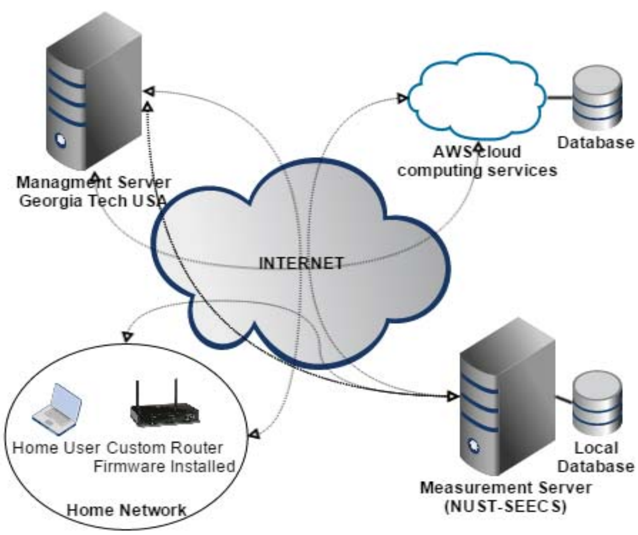

Fig. 2: Network Architecture

and service plans. These routers are mainly deployed in Islamabad, Rawalpindi, Wah cantonment and northern Pakistan. Islamabad and Rawalpindi are considered as privileged sites because of Pakistan's Capital and twin city to Capital. Our deployment measures performance from all of the major landline and fixed wireless broadband ISPs. The deployment also covers almost all variants of technologies providing broadband in Pakistan, from Digital Subscriber Line to WiMax (IEEE802.16d).

A server was deployed at the School of Electrical Engineering and Computer Science (SEECS), National University of Science and Technology (NUST) Islamabad, against which we take latency and throughput measurements. The measurement server ultimately uploads its measurements to an online storage hosted by AWS (Amazon Web Services), where we have made them publicly available. Figure 2 shows network deployment(arrows in figure 2 shows connection between different servers and services) . We performed the following measurements: upload throughput, download throughput, latency, jitter, shape rate and DNS resolution time. We performed latency measurements using ping to a subset of Measurement Lab servers around the world. We also measure last-mile latency of each access link. We measured upstream and downstream throughput of each access link using `netperf` about once every 2 hours (depending on server load), alternating between 1 and 3 parallel TCP threads for each measurement. We also measured traffic shaping of ISP's using `shape prober`. We collected approximately 4.3 Million measurements (see Table III) from both fixed landline and fixed wireless broadband connections. We collect the traces/measurements continuously for period of an entire year. A single measurement represents the snapshot for a given time in which it is measured.

III. Results

This section summarizes the results of our study.We first analyze whether broadband ISPs—both fixed land line and fixed wireless—achieve the levels of performance that they advertise to subscribers. We then investigate both the consistency of performance, as well as other factors that affect performance, such as latency. Finally, we explore the extent to which various optimizations such as DNS caching can improve end-to-end performance in countries such as Pakistan.

A. Does throughput match advertised rates?

We first study whether the throughput values that we measure using our custom router-based throughput measurements match the rate advertised by ISPs to clients. For this purpose, we use *normalized throughput*, the measured throughput on an upstream access link divided by throughput advertised by

ISP	Type	Total	Throughput	Latency	Packet Loss	DNS	Jitter
PTCL	Landline	2177850	6259	1395247	99164	108485	88135
WiTribe	Wireless	1087518	3592	785642	37140	49980	37056
Wateen	Wireless	160237	532	121812	5144	7648	5136
Qubee	Wireless	240984	882	170151	8276	11505	8248
Nayatel	Landline	658043	1666	494568	20033	28808	19994

TABLE III: Summary of Measurements

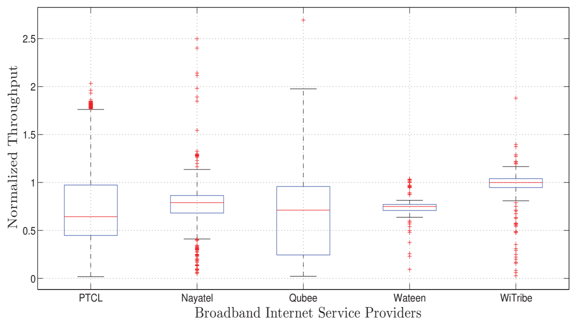

Fig. 3: Throughput of each ISP normalized by rate advertised according to service plan (Value of 1 means advertised rate meets the attained throughput). The box shows interquartile range whereas red line shows median value and whiskers show 10th and 90th percentile values. ***Results show most of the ISPs fall well below the advertised rates***.

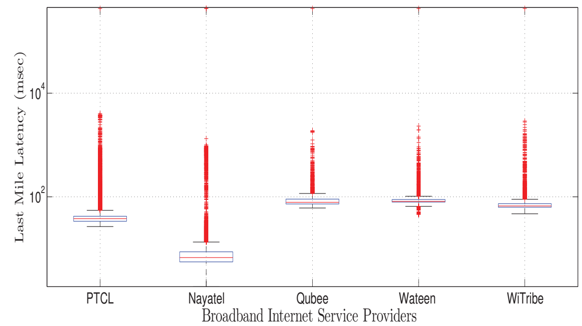

Fig. 4: The last mile latencies for each ISP to server at Islamabad, Pakistan. The boxes shows the Interquartile range whereas redline show the median and the whiskers show the 10th and 90th percentiles. Y-axis is logarithmic scale. The red lines over the whiskers are outliers.

ISP for a given service plan. Figure 3 shows the normalized throughput for each of the broadband service providers present in our data set. The results clearly show that most of the ISPs fail to meet the advertised performance rates. In some rare occurrences, throughput measurements went over advertised rates as shown by whiskers in plot. These results bear some resemblance with those of our previous study of broadband performance in South Africa [18], both of which are in stark contrast to the United States, where ISPs typically meet their advertised service levels. Unlike South Africa, where mobile and fixed wireless providers typically achieved higher albeit more variable rates, the fixed wireless providers in Pakistan generally performed no better than their fixed wireline counterparts, and in some cases (e.g., Wateen) actually offered reasonably consistent performance.

B. Latency Measurements

We study the distribution of latencies between our vantage points and a nearby measurement server. We study both the last-mile latencies in each service provider's access link and the end-to-end latencies that different destinations around the world. Figure 4 shows the distribution of last-mile latencies for various broadband Internet service providers; the y-axis is a log scale and shows latencies in milliseconds. Although the latencies generally show reasonably low variance, there are significant outliers, the whiskers in Figure 4 indicate that there are consistent outliers, sometimes yielding latencies almost an order of magnitude higher than the norm. In general, we note that the last-mile latencies in Pakistan are almost an order of magnitude higher than those from similar measurements we conducted in South Africa. This source of this significant difference certainly warrants further investigation. PTCL has high values of latency because of modem configuration. Modems are configured to operate in interleaved mode instead of fast path mode. In fast path mode modem forwards the packets to DSLAM exactly the same way it received, which results in efficient latency values but it do not perform error correction. Whereas interleaving increases the latency values by splitting data from each frame into multiple segments and interleave these segments among each other which helps in case of burst errors caused because of noise [17]. Typically interleaver depth of 8 adds 5 ms round trip time. PTCL uses interleaver depth of 64 for 4 Mbps connection and 32 for 8 Mbps connection. Figure 5 shows the interleaver configuration of PTCL.

As in the case of our previous work [18], we measured the distribution of latencies to individual Measurement Lab servers around the world, as well as a local server in Islamabad, Pakistan. Figure 6 shows these results. Each bar shows the average latency to the server in the respective region; error bars show standard deviation. The bars are sorted in an increasing distance from Islamabad. As was the case for latency profiles from South Africa, the latencies to different geographic regions do not correlate with geographic distance. For example, latency to New Delhi is between 300-400 milliseconds, even though it is only 686 kilometers away. On the other hand, latency to London is about 200 milliseconds, even though it

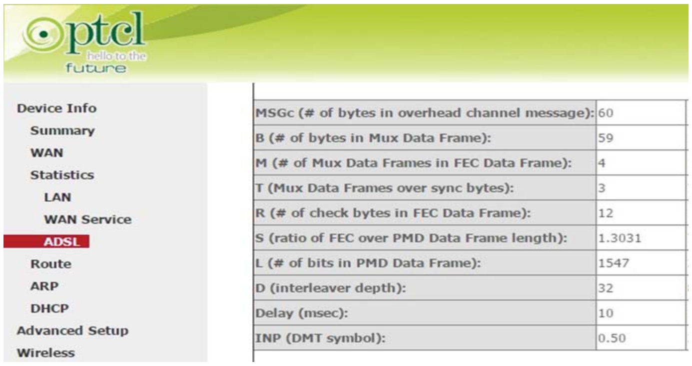

Fig. 5: Interleaver configuration of PTCL (ADSL)

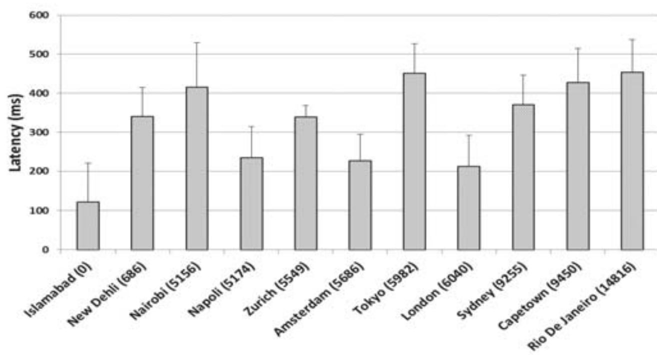

Fig. 6: Mean latencies to the measurement lab servers around the world from Islamabad, Pakistan.

is ten times as far away as New Delhi.

In general, the results show that European destinations are 7 to 8 times farther away from Pakistan relative to New Delhi but their latency values are relatively less. Pakistan does not have any direct routes to ISPs in India: all traffic to India is routed via the Singapore exchange point. Direct, local Internet exchange points could ultimately help reduce latencies between different ISPs in Pakistan and India in order to reduce latencies. This result is similar to that found in previous work [18], which found that paths between Johannesburg, South Africa and Nairobi, Kenya were twice as long as the paths to London, since the routes between these regions were effectively being routed through Europe. In this case, the phenomenon is similar, but the circuitous routes travel through Singapore.

C. What other factors affect performance?

We now explore how factors such as DNS caching at a local resolver and time of day affect the end-to-end performance that users experience. We find that caching the results of DNS queries at a local resolver can significantly reduce the time to resolve the DNS queries—in many cases by an order of magnitude. We also find that local diurnal congestion patterns are far less pronounced than in previous studies in other countries, suggesting that internal to Pakistan ISPs are relatively well-provisioned, but that congestion to international destinations remain significant.

DNS Caching. To measure the effects of local DNS caching on query resolution time, we issue two queries for the same DNS name in sequence to the ISP's local resolver, assuming that the first query will represent the results of an uncached query and the second query will be served from the ISP's local caching resolver. We also perform this experiment to Google's anycast DNS server. Figure 7 shows the effect of DNS caching on broadband performance for cached and uncached queries to both resolvers (DNSC represents DNS cache, whereas DNSNC represent DNS non-cache). The results clearly show that, (1) the latencies for DNS lookups can, in general, be significant, with median values approaching one second for some ISPs; (2) caching the results of DNS queries can reduce the latencies of DNS resolution times significantly, often by an order of magnitude. This result suggests that judicious use of DNS caching and prefetching, such as that which we have studied in our previous work on Web performance [19], could yield substantial improvements in Web performance.

Time-of-Day Effects. Previous studies have shown that local time-of-day dramatically affects network performance. The variation in latencies to various Internet destinations at different times of day results from congestion on the network that becomes more significant during peak times. Previous work has observed similar diurnal trends [18], [20]. We performed the same experiment in ISPs in Pakistan to determine whether the same congestion-related phenomena arise. We took measurements at different times of day against two different servers: a server in Atlanta, GA, and a server in Kansas City, MO.

Figure 8 shows how latency varies depending on the time of day. The results show that latency is both higher and more variable during peak hours. Latency values to the local server in Islamabad are also variable, but variation is significantly less than variation to international locations. The relative stability of latency to the local server in Islamabad, relative to the variable latency to more remote servers, suggests that connectivity between Pakistan and the rest of the world is under-provisioned, and that certain paths within Pakistan (particularly those from our routers in home access networks to the server in Islamabad) remain uncongested. This situation contrasts with both South Africa and the United States, where local networks experience significantly more congestion, presumably because much more content that users are interested in are local to the respective countries (thus resulting in additional local congestion).

Alternative Routes to Global Destinations. Traffic that is routed from Pakistan to global destinations effects not only performance but also reliability. Pakistan is connected to rest of the world via 4 submarine cables i-e SEA-ME-WE-4, SEA-ME-WE-3, IMEWE, and Transworld (TW1). When undersea Trans-cable SEA-ME-WE-4 was cut on 27th march 2013 [21], it disrupted Internet services in Pakistan. The entire traffic was shifted on other Trans-cables. Figure 9 shows increase in latencies observed during the period. This

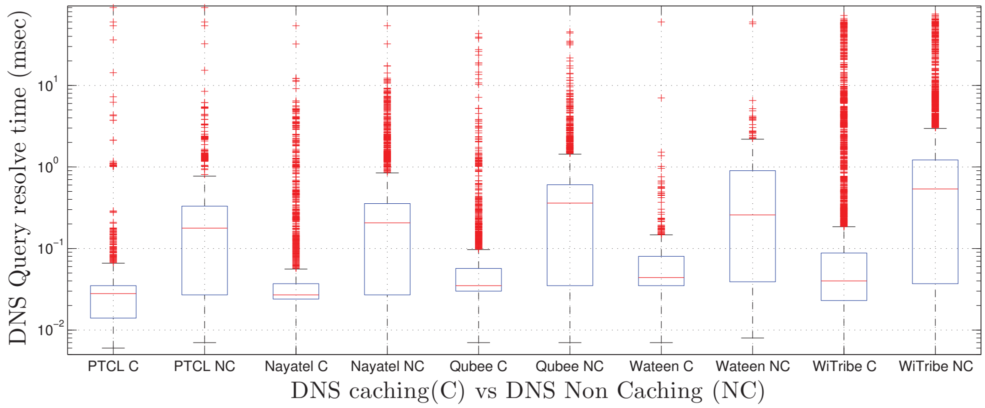

Fig. 7: Effects of DNS caching on DNS query resolution time.

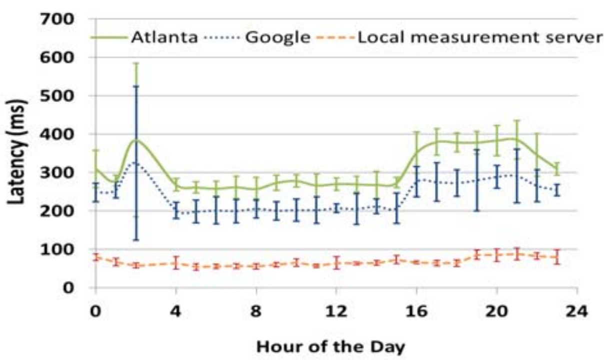

Fig. 8: Mean latency values to the local hour of the day to the servers at Atlanta and Kansas (GOOGLE DNS)along with measurement server at Islamabad. Latency to both servers (Atlanta & Kansas) is high (more than 300ms) and become more inconstant throughout peak hours.

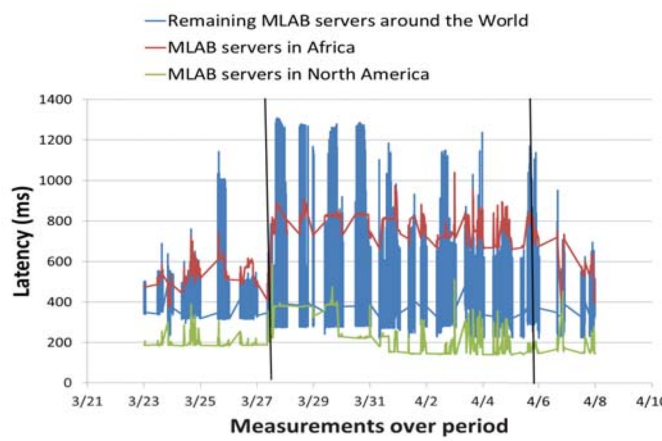

Fig. 9: Increase in latencies observed during period(Vertical black lines), when trans-cable SEA-ME-WE-4 was cut

highlights the need for alternative routes on which traffic should be shifted in case of emergencies in order to make global services available in Pakistan with low latencies to international destinations. The measurement lab servers at different regions in Africa and North America were pinged to get the latency values. A key inference for Pakistan from this incident is the need for more public/private fiber optic cables connecting the country to external world, thus giving the provision to shift traffic to external networks in case of emergencies like fiber cut. A recent initiative under Pakistan China Economic Corridor initiative is a step in right direction to link Pakistan via Khunjerab pass to Chinese fiber network providing additional links in case of such incidents.

Effect of Cross traffic. In order to demonstrate the effect of cross traffic we plot normalized throughput against aggregated throughput. Aggregated throughput is the throughput measured by counting the number of bytes reported by `ifconfig` on the WAN interface of the router while the bitrate measurements were `ON`. This is used to account for cross traffic. Figure 10 shows the comparison between bitrate vs aggregated bitrate. Results indicates that by accounting cross traffic, a handsome amount of increase in bitrates is observed for all ISPs. Similarly like aggregated bit rate we also measure latency underload. ULRTT represents underload RTT. latency underload is latency under heavy traffic conditions. High latency values were observed in underload conditions, as shown in Figure 11.

Effect of Jitter. Figure 12 gives Jitter values for different broadband ISPs in Pakistan. Jitter is the measure of unevenness in latency measurements. High jitter effects real time applications such as gaming, video conferencing, and VOIP services. Wired ISPs having low values whereas fixed wireless ISPs showing higher values with greater variations. Nayatel being the FTTH service provider has the least values than other broadband ISPs.

Traffic Shaping. Figure 13 shows the capacity vs shaping rate plots for different ISPs in Pakistan. Shaping rate and

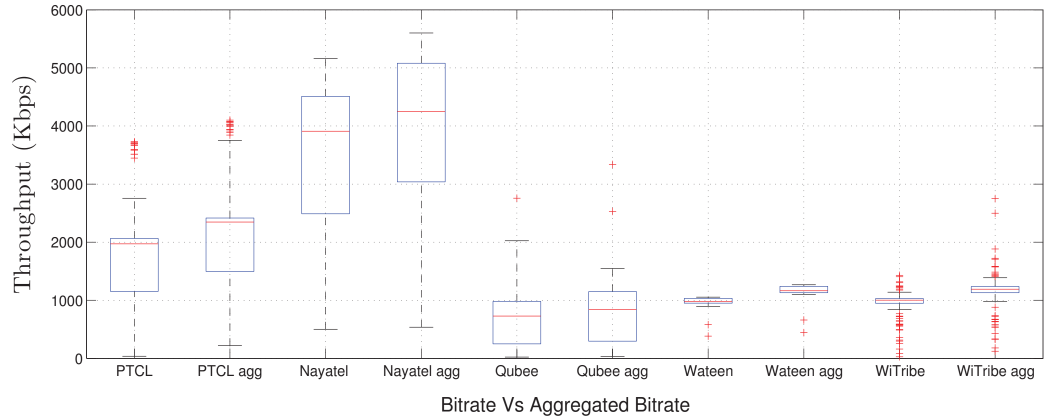

Fig. 10: Bit rate compared to aggregated bit rate for all ISP's (cross traffic)

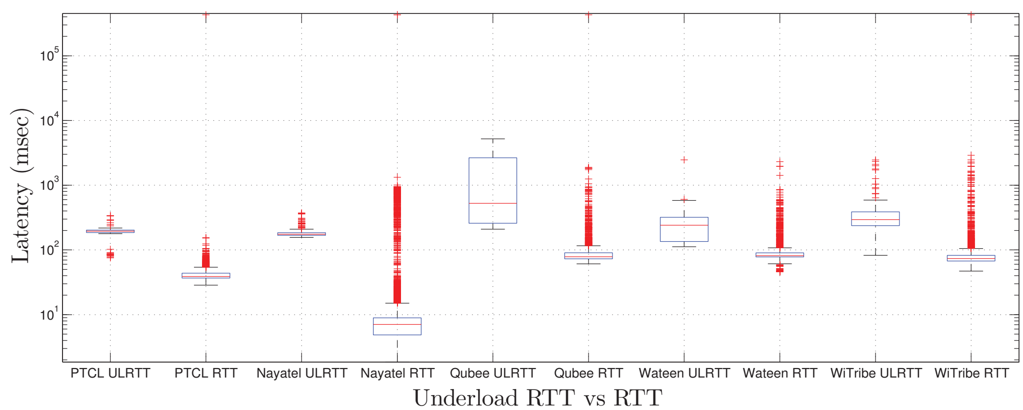

Fig. 11: Underload RTT compared with RTT in normal conditions

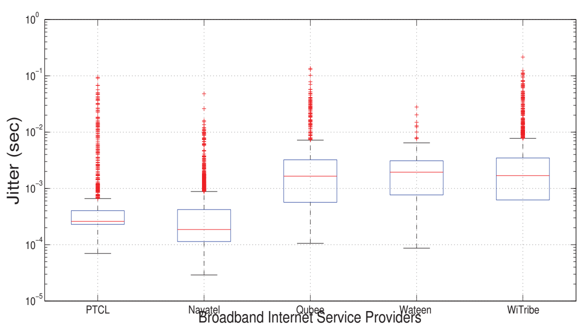

Fig. 12: Jitter values of Broadband ISP's

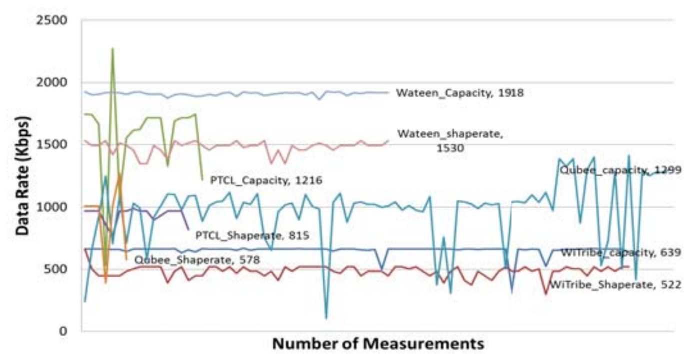

Fig. 13: shaperate vs capacity for different ISP's in Pakistan

capacity were determined and measured using `shape prober` tool. Results shows that traffic rate is less than that of available capacity. So, it is evident from results that ISPs in Pakistan performs traffic shaping for improving latency and bringing them in compliance with a desired traffic profile.

IV. Discussion & Conclusion

Our emipirical results can be summarized as, (1) ISPs are not achieving their advertised rates; (2) Factors such as latency can have significant effects; (3) Poor peering between local ISPs in a region, generates circuitous routes; and (4) Certain simple optimizations such as local caching and prefetching can significantly improve DNS response time—we make several observations recommendations for broadband networks in Pakistan.

One of the more unique observations about the infrastructure of Pakistan— especially relative to similar studies that we have performed in the past—is that the country appears well-provisioned relative to the internal traffic demands in the country. Given that Pakistan has clear latency bottlenecks to almost everywhere in the world, the country should consider making significant investments in infrastructure that can move content closer to users in the country, perhaps with the deployment of local caching infrastructure. Among Top 500 Alexa sites on the web, only Google cache content locally in Pakistan. As the results of the DNS caching experiment suggest, aggressive prefetching and caching of DNS records either in the local ISP or in the home network itself (as we have done in previous work [4]) may significantly improve end-to-end performance for users. It remains to be seen, of course, whether the local networks would become just as congested if content are shifted to them.

Additionally, although the internal networks appear relatively well provisioned, they also appear to exhibit tremendously high latency. We saw median latencies to local servers on the order of 100 milliseconds, significantly higher than latency one should expect to see to a local server. This result requires more study, as it may suggest that local peering within Pakistan is unusually sparse (a result that would not be surprising, given that local ISPs would have little to no incentive to peer with one another if no local ISPs were hosting any content that local users were requesting.

Finally, despite relatively poor peering to most places (and especially nearby countries such as India), Pakistan enjoys relatively rich connectivity to parts of Europe, as well as parts of Google's network. Although the lack of extensive peering in Pakistan might come as no surprise, what is somewhat surprising is the good connectivity that exists to certain networks and regions (e.g., Europe, Google's backbone network).

This paper presented a comparative study of broadband access performance measurements in Pakistan, inspired by similar studies that we have performed in the United States and South Africa. Based on successful studies in these countries, we employed a similar method to perform measurements of broadband performance across a diverse set of ISPs within the country.

Our study has yielded some results that are similar to those from other countries and others that are markedly different. For example, as we saw in South Africa, we observed many circuitous routes to servers in nearby geographies, although these routes often detoured through Singapore (as opposed to Europe, as was the case with local or regional routes within Africa). The latencies that we see between Pakistan and the rest of the Internet are high enough that they likely prevent reasonable user experience in many cases. Although increasing peering within the country and with other regional ISPs is a natural long-term solution, a more immediate step may be more aggressive cache deployments and prefetching strategies that can circumvent functions that would otherwise be extremely high latency (e.g., resolving DNS names). As in many regions, most users in Pakistan would likely experience better Internet performance not only from locally cached content and aggressive prefetching, but also from richer peering and interconnection agreements, such as those that might be enabled by emerging Internet exchange point designs.

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