Measuring Broadband Performance for Home Users in Pakistan using BISmark*

Muhammad Faheem Awan, Saad Qaisar
School of Electrical Engineering and Computer Science, NUST
Islamabad, Pakistan
(10mscsemawan,saad.qaisar)@seecs.edu.pk

ABSTRACT

Even though broadband Internet enjoys wide penetration in Pakistan, performance of fixed and wireless broadband has not been thoroughly investigated upon from an end user's perspective. To the best of our knowledge, no independent study exists to date documenting home user broadband experience in Pakistan. This dearth of evidence is noteworthy since regularly observing and checking broadband performance is fundamentally important both for consumer and regulatory consumption, most importantly to keep a check if users are getting services they are paying for and regulators can make conversant decisions. To address this gap, we conducted a pilot study of both fixed and wireless broadband connections in Pakistan through deployment of programmable wireless routers for home users. Our findings suggest that consumers in Pakistan are not getting advertised speeds, wireless broadband leaves behind fixed broadband in areas where both are available, and speed is not the only limiting factor on performance. Our results show that monitoring broadband performance provides enough information for consumers and policy-makers alike. Finally, limiting factors such as latency mean that investing in local server infrastructure will also go a long way in refining broadband experience for Pakistani users. Our contribution to information and communication technology community includes first systematic study of broadband performance in Pakistan that can serve as an example for monitoring broadband performance in similar developing countries.

Categories and Subject Descriptors

C.2.3 [**Computer-Communication Networks**]: Network Operations-Network Management; K.4.1 [**Computers and Society**]: Public Policy Issues— *regulation, performance measures*

General Terms

Performance, Measurement, Management

---

*This work has been carried out in collaboration with Project BISmark (Broadband Internet Service Benchmarking).

Keywords

Broadband performance, quality of service, consumer protection, internet benchmarking

1. INTRODUCTION

Since wide-spread adoption of Internet, a community of researchers has focused their efforts to improve and evolve the technology. A significant amount of research is dedicated to improve access network quality for an end-user. In Pakistan, broadband service adoption is on a fast lane. All major service providers (ISPs) are advertising new data packages at increasingly lower cost in order to capture market. Despite increase in broadband penetration in Pakistan, very little knowledge exists about country's broadband performance. Broadband users and authorities do not have access to systematic assessments particularly from a home user's perspective. This dearth of substantiation is troublesome, aside from cost [1], if performance is not up to mark, it affects usage of broadband [2, 3] resulting in decline of country's development indicators [4]. In order to discourse this space between authorities, users and broadband providers, a need for measuring broadband performance arises in Pakistan in order to ensure that ISPs fulfill their promise of advertised rates, users use reliable connection and officials can undertake informed decisions [5, 6, 7]. Hitherto, to the best of our knowledge, no methodological independent study of fixed broadband land line/wireless Internet performance has been steered in Pakistan for home users. This manuscript aims to address this gap as a first step, facilitating users, broadband providers and regulators towards improvement of Internet infrastructure. Our main objective is collecting realistic evidence about quality of broadband connectivity in Pakistan.

The following questions were under observation.

- Are home users getting what their Internet service provider (ISP) is advertising to offer them?

- Are users attaining steady performance?

- What are other factors except throughput that affect broadband performance?

1

In order to answer these questions, in the first phase, we deployed custom home network routers at 15 different testing sites in Northern region of Pakistan, incities of Islamabad (capital city), Rawalpindi, Abbottabad and Wah. Islamabad and Rawalpindi are considered as privileged localities with high-end users having set-up of almost all major ISPs located within the city or premises. On the contrary, Wah and Abbottabad represent lesser developed urban settings. The routers are given to users having different ISPs and service plans helping gather throughput and latency measurements over a period of 4 months from last quarter of 2013 to early 2014 with approximately 10 measurements on daily basis.

Through the course of our study, we gained some fundamental insights which may be interesting both to end-users and research community. First of all, majority of customers are not getting the service which they are paying for i.e. they are not achieving throughput rates that are advertised to them by their service providers. These results so attained controvert to results of studies conducted similarly in developed countries such as United Kingdom & United States [7] and are in line with a recent study in developing world by Feamster et al [8]. Regions where both landline and wireless (fixed) operate, wireless (fixed) outperforms landline. This explains the exponential growth in number of consumers using fixed wireless broadband [9]. Third, and conceivably utmost significant, throughput that an ISP offers is only part of story, equally important is latency to websites and services that users actually visit. Physical distance of users from servers of most popular websites like Facebook, Twitter etc. generates latency values in several hundreds of milliseconds resulting in unreliable performance of an ISP. For servers physically far away with routes to servers profound result in low values of latency.

Our findings infer that benchmarking ISP performance in a country enlightens both customers and regulators. Regulators and policy makers can provide favorable environment so that companies invest in creating local servers or servers nearby for popular websites like Facebook in order to reduce latency values which in turn enriches user experience.

Rest of the paper is structured as follows. First of all, we discuss motivations and background of our study. We present metrics and methods used for measuring broadband performance. We sketch advantages of our approach for measuring broadband performance compared with alternative approaches. We describe challenges faced during period of measurements typical in developing countries. We present our method and results of our ongoing study aiming to benchmark ISPs (land line and wireless (fixed)) across Pakistan. Finally, we provide recommendations for improvement in prevailing conditions and conclusion.

2. BACKGROUND

In this section, we present inspiration for measuring broadband performance along with common metrics and methods used. We also discuss context of broadband in Pakistan.

2.1 Need for measuring broadband Performance

Increasing broadband penetration in Pakistan necessitates independent benchmarking of ISPs in order to improve home networks. Measuring broadband performance is also significantly important for auditing and accountability of ISPs. Measuring broadband performance will help in order to fulfill gap between planned and achieved rates. This will help authorities in terms of regulating ISPs. Measuring broadband can also facilitate service providers in terms of investment, where they can invest in order to improve the network.

2.2 Broadband in Pakistan

Pakistan is on fast lane in terms of broadband Internet. In Pakistan, there are nearly 30 million Internet users with penetration rate of 16% [10]. There are almost 50 Internet service providers [10] where number of customers using broadband is nearly 2.2 Million [11]. Pakistan Internet user's growth rate is 2nd highest in SAARC countries in accordance with its population [11]. Broadband in Pakistan includes fixed line via Digital Subscriber line (DSL), Fiber to the Home (FTTH), 3G USB modem and WiMax (IEEE802.16d) connections.

Pakistan is less progressive in terms of regulating in spite of greater Internet penetration rate. In Pakistan, broadband policy was drafted in December 2004 [12]. After 2004, number of ISPs came into existence and broadband shot in popularity. Even though policy exists since 2004, there are no significant updates on policies that were drafted in 2004. For instance, the policy draft does not address how quality of broadband is monitored and regulated. Our study will help authorities in order to draft new policies for continuous monitoring and regulation of broadband ISPs.

3. DATA COLLECTION

In this section, we describe metrics and methods typically used for measuring broadband performance along with datasets available. We describe tools we implemented for measuring broadband performance and how we recruit users for this study. At the end of this section, we list down challenges we experienced and how we address these challenges.

3.1 Metrics and Measurement Methods:

We define metrics and approaches used for computing broadband performance.

3.1.1 Performance Metrics

Most widely used metrics for measuring broadband performance include download and upload throughput, latency, jitter and packet loss. Upload and download throughput are generally referred as upstream and downstream throughput [13, 5, 7].

Download speeds are a measure of Internet traffic towards the user from local or international servers and is measured in Megabits per second (Mbps). Slow download speeds affect file downloading, streaming videos and other online applications that require high download speeds.

Upload speeds measure the transfer of Internet traffic from user towards local or international servers and is measured in Mbps. Upload speeds affect real-time interactive applications like video conferencing, voice chat, online gaming etc.

Latency is the measure of round trip time taken by a packet from source to destination and back, measured in milliseconds (ms). Latency mostly distresses real time applications such as VOIP and online gaming. Online gaming is intolerably affected by high latency values.

Jitter is the measure of un-evenness in latency measurements. High jitter affects real time applications such as gaming, video conferencing, and VOIP services.

Packet loss is number of packets that fail to touch the destination either resulting from upstream or downstream. Packet loss is measured in percentage of loss. High percentages of packet loss degrade performance of broadband connection.

Upload and download speeds are measured by sending a file from source to destination and calculating time to reach the destination. Similarly, latency measurements are taken by using PING and FPING tests. PING and FPING are network functions that send file to the destination and wait for a response. Jitter has been calculated using measure for change in latency. These are most viable and accepted methods and metrics used for measuring broadband performance [14].

3.2 Measurement Approaches

Number of methods and techniques are used in order to measure broadband performance. One method is taking measurements from the end host. Such types of measurements are called host-based measurements. They are mostly called active measurements since they involve continuously sending or receiving data on user's broadband connection. These types of measurements can be done by asking user to download a specific application [13] on end machine and then running web application gives speed tests for upload and download throughput along with latency. The most prominent web application is identified as *speedtest.net* produced by OOKLA [15]. There are also other content distribution services for performing host based speed tests like
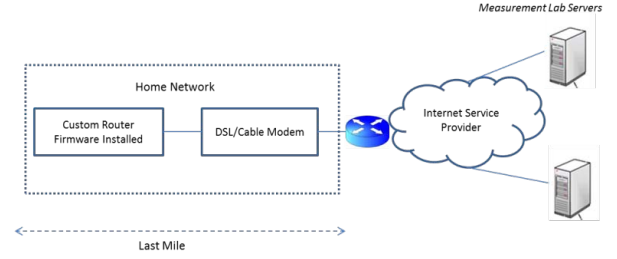

Figure 1: Gateway View for ISP measurement

Akamai [16]. The host based measurement is always affected by certain limitations. Because of end user, measurements can be affected by home network environment like home wireless network, processing power of end machine and multiple users accessing same connection. The measurements depend on user to start and represent snapshot of measurements at specific time [17]. Such types of measurements vary continuously and cannot provide exact or accurate measurements. These measurements may be higher or lower than performance over time [5].

In contrast to host based measurements, other approach is that of router based measurements. 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 custom router or connect custom router along with default router at a site whose broadband performance is to be measured such as private residence (see Figure 1). The advantage of such type of measurement is that router is always on and connected to the line resulting in continuous measurements without any intrusion from a user. These tests produce cleaner and more accurate measurements since home factors influencing measurements are accounted for [18]. 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 a network. Host based and router based, both type of measurements report to server usually at remote location where these measurements are envisaged, examined and grouped for reports.

3.3 Existing Measurements in Pakistan

There is scant data available regarding broadband performance in Pakistan from a home user's perspective. For instance, the RIPE Atlas project [19] uses custom probes for analyzing Internet measurements though in Pakistan, only 2 probes are registered with the project for measurements. Similarly, host based measurements for different countries including Pakistan are available from OOKLA [15] and Akamai [20]. According to OOKLA Net index, Pakistan falls on 174th

DataSet	CollectionPeriod	Measurements
Custom Router	September 2013 - Mid-January 2014	Latency, Throughput (Uplink & Downlink), Packet Loss, Jitter, Latency to Local and International Servers

Table 1: Summary of dataset used in study

position with average download speeds of 2.3 Mbps and falls on 170th position with average upload speed of 1 Mbps [21]. Akamai (Q4 2013 report) [20] reports average connection speed of 1.4Mbps and broadband adaptation rate of 1.2 percent in Pakistan [9].

Regardless of OOKLA and AKAMAI statistics having thousands of record points, they do not provide in depth analysis of broadband performance in a specific country regarding: user's broadband service provider, user's service plan, variation in performance over time and performance issues. Our study may have less data points than OOKLA and AKAMAI given the cost and number of tools available, it gives more insight on home user's experience since router based approach takes measurements from inside a home over time and gives a clearer picture of both land line and fixed wireless broadband performance.

ISP	No of Users	Total Measurements	Latency measurements
PTCL	6	102396	75665
WiTribe	3	260190	188572
Wateen	3	54661	39918
Qubee	1	180939	126083
Nayatel	2	173002	173002

Table 2: Custom router deployment against ISP and users

3.4 Data Collection: Deployment and Tools

We collected data sets from September, 2013 till Mid-January 2014 in Pakistan (see Table 1). We collected data from both fixed land line and wireless broadband connections for a given period of time using custom routers in collaboration with project BISmark [22]. Measurements for different ISPs differ from each other as user behavior to turn on or off the router vary. When router is "ON", it reports to the server.

Custom Router

In order to achieve our goals, we deployed 15 routers across different regions in Pakistan. These routers provide a sample of traffic for three major provinces of Pakistan including Punjab, KPK, and Federal Capital Territory. These routers are deployed at residential sites. Each site is equipped with a custom router. These routers are deployed in a fashion that they cover all major landline and fixed wireless broadband ISPs. They cover almost all variants of technology providing broadband in Pakistan, from Digital Subscriber Line to WiMax (IEEE802.16d). These routers take throughput and latency measurements continuously over time and report back to a measurement server, established at Islamabad, Pakistan. Along with deploying routers, we also distribute questionnaire among users, asking about their broadband service plans, their current experience and remarks about Internet speeds. We manage these routers through online custom upgrades via a management server located at Georgia Institute of Technology, USA. Continuous measurements are performed by routers (see Table 2). Latency measurements were performed against different measurement lab servers present across the world.

3.5 Challenges

Challenges are always an integral part of work, specifically in third world countries like Pakistan. The most pressing challenge is having most of the customer plans with data caps on their broadband connections. In most of the cases, customers tend to blame custom routers for exceeding data cap limits which may not exactly be the case. This limits extent of data sent from user devices to server. Thus, it is important to carefully select data for sending to the server. Most frequent measurements may give in depth insights but result in exhausting data cap for a user, thus appropriate tradeoff needs to be maintained.

Second, we had to ensure routers are "ON" for most of the time. Users tend to unplug the devices when not in use. We had to engage users in the study in order to keep devices "ON" with frequent follow ups through email, phone and personal contacts. We had to ensure that our devices do not interrupt users' Internet access and take measurements for a short span of time (typically less than 15 sec).

Another significant challenge was user's privacy concerns. Most of the users were concerned about their privacy. In order to engage users in the study, data collected from user devices is also made available to them so they can download their data gathered by routers. This allayed some of the user concerns giving them surety that no browsing data is recorded.

4. RESULTS

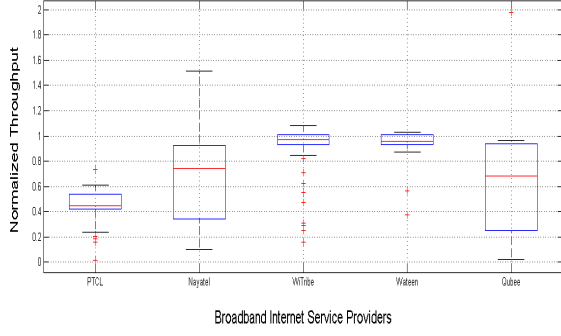In this section, we share the results of our study.

Figure 2: 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 shows most of the ISPs fall well below the advertised rates***.

First, we present whether broadband ISPs, fixed land line and wireless, fulfill promise of service advertised to customers. Subsequently, we investigate steadfastness in performance and other factors that affect performance, such as latency to different international servers and services. We observed fixed (landline and wireless) broadband for five major broadband service providers in our dataset. To complement, we take feedback from users regarding their broadband speeds through email questionnaires.

4.1 ISP's fulfilling promise of advertised rate or not:

By use of our custom routers data, first we study whether throughput of different router tools matches advertised rate, claimed by ISPs to clients. For this purpose, we use concept of normalized throughput: throughput attained by customer divided by throughput advertised by ISP for a given service plan. Figure 2 shows normalized throughput for each of the broadband service providers present in our data sets. (The caption below figure shows how to interpret boxplot). As results indicate, most of the ISPs fall below their advertised rates. In some rare occurrences, throughput measurements went over advertised rates as shown by whiskers in plot.

For further analysis, we investigate different grievous cases where advertised rate does not meet attainable rates. Figure 3 shows throughput measurements timeline for almost three months for one of the case. In this case, ISP advertised service plan was of 2 Mbps though results so attained are well below advertised rate (less than a quarter). This case falls under one of the extreme cases we analyzed. Similarly, from our
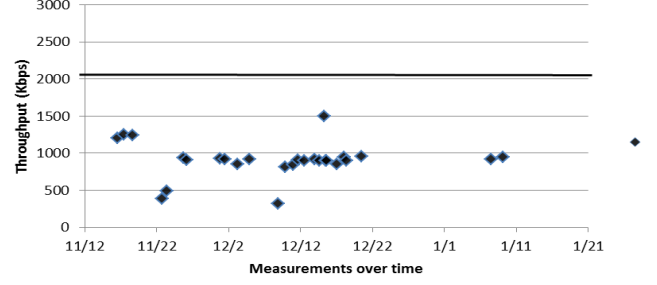

Figure 3: Timeline of throughput measurements from a PTCL user, in North Pakistan over a course of time. The advertised downstream throughput for this user is 2Mbps (2048 Kbps). Unfortunately the users only get 1Mbps during the entire time.
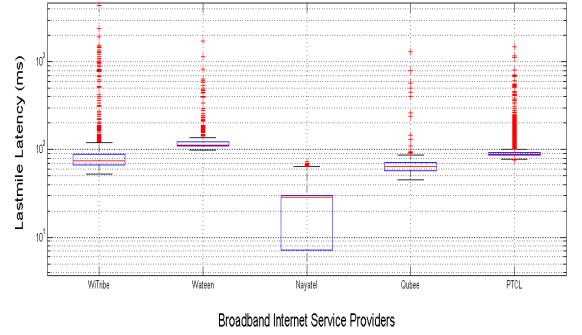

Figure 4: The latencies for each ISP to server at Islamabad, Pakistan. The boxes shows the Interquartile range whereas redline show the median and the whiskers show the 10th and 90th percentiles. Y-axis is logarithmic scale. The red lines over the whiskers are outliers.

data collection, we also study distribution of latencies from different service providers to measurement server. Figure 4 gives box and whisker plot of latencies for different ISPs, y-axis is log scale. These values envisage farfetched variable latencies and in some cases very high latency values, as shown by whiskers in Figure 4.

User Insights

Custom router users were asked for their current experience regarding most common Internet activities. Over sixty percent of the users reported that speeds are sufficient for Internet activities like using Facebook, email, instant messaging, browsing news websites etc. Many users reported speeds well below an acceptable level for streaming activities like videos on daily motion, vimeo etc. with no data available for YouTube courtesy blockage in Pakistan. They also reported their connection speeds not meeting requirement of efficient video

Figure 5: Download throughput for different Wireless broadband ISPs against the local server at Islamabad, Pakistan.Nearly all the ISPs experience the same throughput.
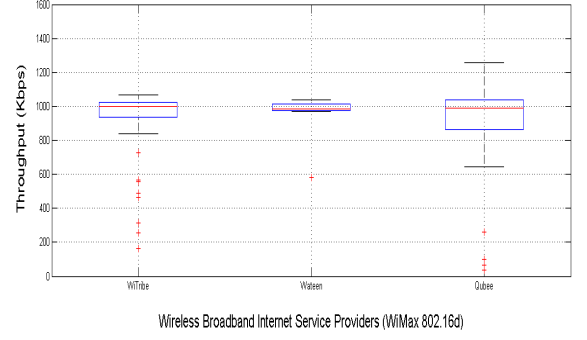

Figure 6: Download throughput for different Wireless broadband ISPs against the International server in London. Nearly all the ISPs experience same throughput but little less than that of local server.
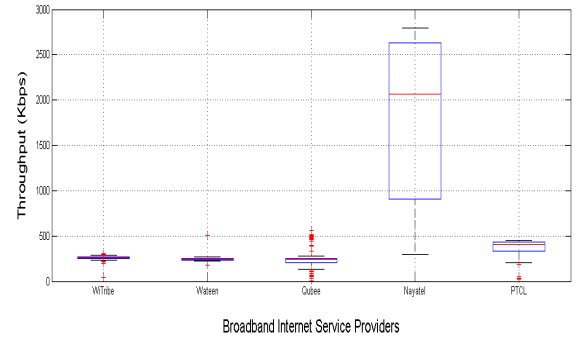

Figure 7: Upload throughputs of different broadband ISPs .

chat. Users were also asked about downloading via torrents, uploading or downloading photos and videos. In this case, we got a mixed response some users giving positive and some others, negative reply. These findings provide an indication that users are not happy in general with their current Internet speeds and speeds are not up to customer satisfaction for bandwidth intensive activities.

4.2 How well wireless broadband perform

From our dataset, we calculate downstream throughput for different fixed wireless broadband service providers against local server at Islamabad, Pakistan and also against an international server at London, United Kingdom. Figure 5 shows results of downstream throughput against local server whereas Figure 6 shows result of downstream throughput against the international server. The results clearly depict that interquartile ranges for different wireless broadband ISPs are not that large. There is very less variation in download throughput for both cases. Qubee has larger interquartile range than Wateen and WiTribe showing greater variations. Similarly, download throughput against local server is greater for all ISPs with fewer variations whereas against international server, download throughput is less in comparison with local server. Also, greater variations in download throughput are observed for international server (London).

Upload speeds

Upload throughput of all ISPs available in our data set is plotted in Figure 7. The upload speed for WiTribe, Wateen, Qubee is plotted against their service plan of 1 Mbps whereas PTCL is plotted against service plan of 2 Mbps and Nayatel against 3 Mbps. These are service plans for download throughput and upload is not usually defined in the plan. Customers usually care less about upload speeds unless highly constrained. Naya-

tel provides maximum upload throughput with larger interquartile range, showing a lot of variations, whereas remaining ISPs with small interquartile ranges show less variations and nearly constant upload throughput values.

4.3 Which is reliable: Landline or Fixed Wireless Broadband?

The comparison between fixed (landline and wireless) providers is to be made by considering following scenario. Both land line and wireless broadband ISPs are tested for throughput measurements from same location to measurement server at Islamabad, Pakistan. Figure 8 gives throughput measurements from same location to measurement server whereas Figure 9 gives latency measurements from same location to measurement server. Figure 8 clearly depicts that for a region where both fixed land line and wireless (Fixed) broadband is available, wireless outperforms fixed land line.

Figure 9 shows distribution of latency measurements. Key take away here is that latency for landline is also
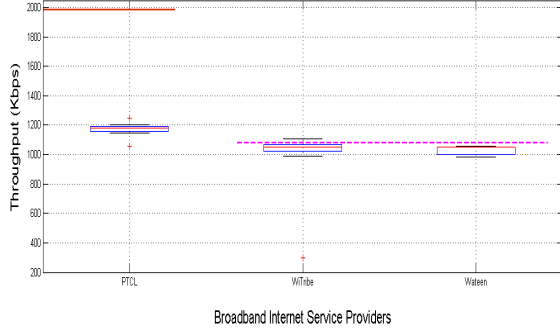
Figure 8: Downstream throughput measurements of one fixed land line (PTCL) and two wireless (WiTribe and Wateen) fixed broadband from same geographic location to measurement server at Islamabad, Pakistan. The red line above PTCL shows service plan against which it is plotted, similarly dotted line above WiTribe and Wateen. The fixed landline throughput is considerably lower than wireless broadband (Fixed)
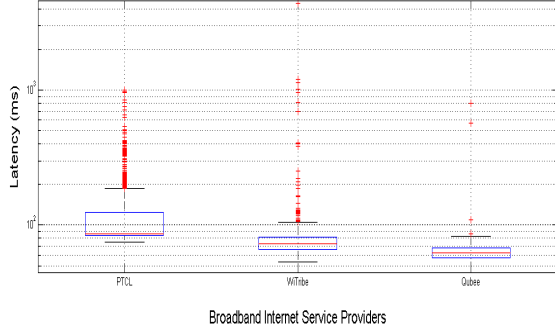

Figure 9: Latency measurements for one fixed land line (PTCL) and two wireless broadband (WiTribe & Wateen) from same geographic location to measurement server at Islamabad. Y-axis is log scale. Fixed land line experiences high latency values than wireless broadband.

higher than that of wireless broadband. Y-axis is log scale, hence even small change is prominent.

PTCL is the dominant broadband service provider in Pakistan, we picked up customers from different regions and plotted throughput against their service plan in order to see whether PTCL performance degrades overall (see Figure 10). Similarly in Figure 2, we used the concept of normalized throughput. A result clearly depicts that most of the PTCL customers are not attaining rates which PTCL promises.

In order to compare fixed land line and wireless broadband, we also plot downstream throughput in terms of cumulative distribution function. Figure 11
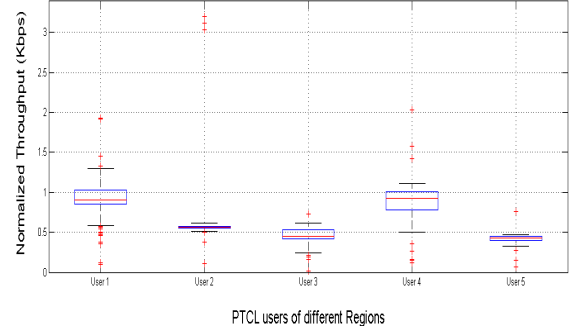

Figure 10: Normalized throughput of PTCL users from different regions. Throughput of the users is normalized by the rate advertised to them. 1 means attained rate is equal to advertised rate
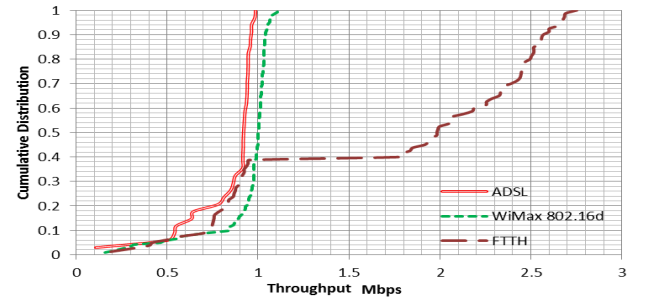

Figure 11: Cumulative distribution of download throughput of different fixed landline and wireless technologies in our dataset. FTTH is plotted against the service plan of 3 Mbps whereas ADSL against 2 Mbps and WiMax against 1 Mbps. WiMax and FTTH give higher throughput than ADSL.

gives cumulative distribution function of various technologies used in our custom router data set. Results clearly depict that WiMax IEEE802.16 d provides better throughput measurements than that of Asymmetric Digital Subscriber line (ADSL) in regions where both are available. Nayatel (FTTH) also performs well but its coverage is only in capital city Islamabad, Pakistan. This performance aspect can be attributed as one of the main reasons for rapid growth of WiMax in Pakistan [9] where both fixed line and wireless are available.

To summarize results of router based measurements, most of the ISPs do not appear to fulfill QoS demands they claim. WiMax outperforms landline (ADSL) where both are available.

4.4 Other aspects affecting performance:

Now we look how factors such as distance of inter-

national servers, time of day when user uses broadband connection and latency to popular services affect performance of broadband connection. Amusingly, we found that users attain degraded performance to popular websites and services because of high values of latency as various servers have high latency path to Pakistan. This high value of latency may not mean that geographically, these servers are far away. Connectivity between different ISPs is not as dense in Pakistan as in other areas of the world. These subjects are discussed in detail further below.

4.4.1 Network paths from worldwide servers to users (Latency to various servers)

Figure 12 gives the average latencies to measurement lab servers around the world from custom router users. The bars in Figure 12 give average latencies and numbers with name of city showing distance from Islamabad. The bars are sorted in an increasing distance from Islamabad. Fascinatingly, values of latency do not depend upon geographic distance. For example latency to New Delhi is around 300 to 400 millisecond which is only 686 Kilometers away but latency to London is around 200 to 300 millisecond which is 6040 Kilometers away. The results depict that European destinations are 7 to 8 times farther away from Pakistan relative to New Delhi but their latency values are less as compared to New Delhi. In order to investigate paths, we use trace-route network measuring tool which traces paths of routed traffic. In case of New Delhi, India, Pakistan does not have any direct route with ISPs in India, all traffic routed to India is via Singapore exchange point. Thus, direct exchange points are required between different ISPs in Pakistan and India to reduce latency measurements. Similarly, in case of Nairobi, Cape Town and Rio de Janeiro, there are no direct routes. Traffic to Nairobi, Cape Town and Rio de Janeiro is routed via European Exchange Points. Thus a direct routes along with ISPs collaboration and peering is required to reduce latency values.

4.4.2 Latencies to well-known websites:

We calculated latencies to popular websites. Most of the users experience latency values more than 300ms to five of popular 10 websites: LinkedIn (413ms), Yahoo (400ms), Amazon (697ms), Facebook (529 ms), Wikipedia (353ms). Surprisingly, our users' experience and perceptions were sound concerning access to these websites (section 4.1). However, these latencies suggest that servers for these websites are mostly present in America and Europe. Previous studies show that these values of latencies are high enough and affect users' broadband experience [23, 4]. These high values of latencies can be decreased by deploying web caches geographically near or by improving connections between
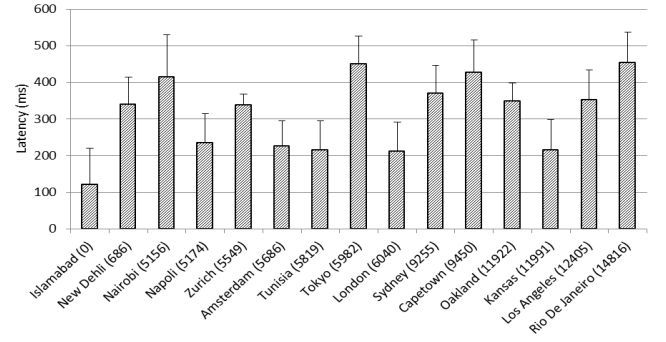

Figure 12: Mean latencies to the measurement lab servers around the world from Islamabad, Pakistan. Numbers along with the city name reflects the distance in kilometers from Islamabad. The bars are sorted as in increasing distance from Islamabad.
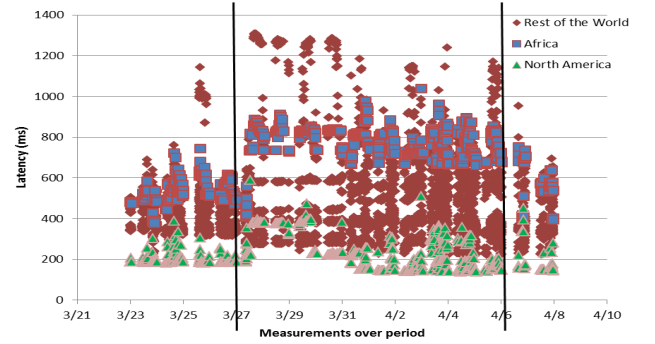

Figure 13: Increase in latencies values during the period when Trans-cable SE-ME-WE-4 was cut.

Internet service providers via native interchange points.

4.4.3 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 Trans-cable SEA-ME-WE-4 was cut on 27th march 2013 [24], it disrupted Internet services in Pakistan. The entire traffic was shifted to other Trans-cables. Figure 13 shows increase in latencies observed during the period. This 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.

4.4.4 Time of Day

Previous studies have shown that local time of day affects network performance dramatically. This is be-
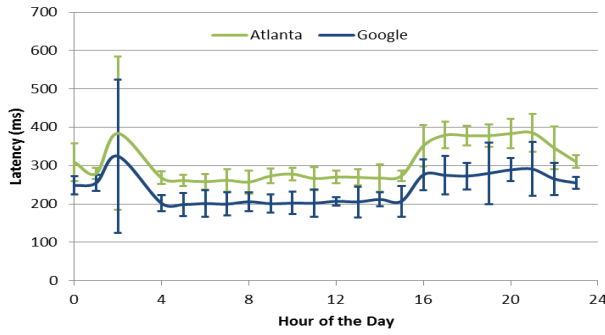
8

Figure 14: Mean latency values to the local hour of the day to the servers at Atlanta and Kansas (GOOGLE DNS). Latency to both servers (Atlanta & Kansas) is high (more than 300ms) and become more inconstant throughout peak hours.

cause at peak hours, networks became more congested [14] due to which performance sees a hit. We analyzed whether same behavior is experienced in Pakistan or not. We took measurements at different times of day against two different servers, one at Atlanta, US and other at Kansas, US (Google DNS). Figure 14 shows latency against local time of the day. Results depict latency values increasing and becoming more variable during peak hours.

5. DISCUSSIONS AND RECOMMENDATIONS

On the basis of findings from our study, we present following takeaway points and recommendations in order to enhance broadband performance in Pakistan.

- The ISPs are not fulfilling their promise of advertised rates to users in Pakistan.

- The regions where both land line and wireless (fixed) broadband connections are available; wireless broadband outperforms land line.

- Throughput is not only limiting factor in broadband performance; latency values to international servers also affect broadband performance.

Keeping these insights in perspective, we provide following strategy recommendations for Pakistan.

5.1 Measuring broadband performance in Pakistan is beneficial for customers, ISPs and regulating authorities

From our continuous routers data set, it is evident that most of the customers do not achieve rates that are advertised to them by their ISPs. The regulating authorities are required to develop frameworks that result in continuous monitoring of broadband services to home users in Pakistan. We provide methods to develop such a framework. Our method will help regulators to draft regulating policies continuously and will help customers and ISPs to be enlightened in terms of services. Thus, we recommend ways and approaches for continuous measurement of broadband connections in Pakistan that will help customers, ISPs and regulators to take informed decisions.

5.2 Private investment in local infrastructure

Regulators should assist in aiding private investment in local infrastructure. Our findings suggest that throughput is not only cause for performance degradation in Pakistan. Latency to international servers and services also affect user's experience particular to well-known and popular websites. Thus authorities, in spite of increasing throughput rate in the country should provide maximum incentive to private investors to invest in local infrastructure in or near Pakistan. Authorities should also provide favorable environment for peering between different ISPs so that content can be fetched quickly. Whichever of these, will result in reduction of latency values. Reducing distance to international Internet content for consumers in Pakistan will definitely enhance users experience. Regulators should create environment that private investors may invest in following categories in order to decrease latency values.

5.3 Creating favorable environment for native versions of prevalent services

Pakistan already has some local versions of international services that are popular like olx.com.pk, google.com.pk, travian.com.pk. The state can help create a favorable environment in order to improve local versions of international services. This can considerably improve performance of broadband connections in Pakistan.

5.4 Reducing distance to content by creating local data centers

Authorities should make efforts and provide incentives to private investors in order to create local data centers for users in Pakistan. State cooperation with popular service providers to build up data centers that are geographically closer to Pakistan should be encouraged. This will help enhance performance for popular services in Pakistan.

5.5 Peering between ISPs:

Authorities and private entities should make an effort in order to create multiple exchange points between different ISPs. This will result in traffic exchange locally .For example, in case of route to New Delhi, it was tra-

versed via Singapore. If local exchange point is created between ISPs, it will make performance of broadband connection better in Pakistan and India, both.

6. CONCLUSION

We have presented results of our study for fixed landline and wireless broadband performance in Pakistan. Our results indicate that (a) ISPs are not fulfilling the promise of advertised rates to users (b) Wireless broadband outperforms fixed land line where both are available (c) Throughput is not the only reason for degradation in broadband performance, latency to prevalent websites and services also plays a vital role in performance deprivation (as defined in terms of geographic distance and ISP peering). Thus, many encouraging Internet aspects guaranteed by ISPs are not recognized in Pakistan and a number of problems associated with latency and throughput degrade broadband performance.

We advise regulators to implement continuous monitoring of broadband Internet service providers either by using router based or host based measurement methods at a number of locations and service plans. Initiatives should also be taken for investment in local infrastructure to bring international content and services closer to the country users.According to BCG e-friction index model [25] Pakistan lies at the top with high e-friction score of 82, topping mostly all the countries except Nigeria. High e-friction countries are in great risk of missing out on a high-impact stimulant of growth and job creation. We hope that our contribution in benchmarking ISPs of Pakistan will benefit end customers and help regulators to make informed decisions. It will also provide insights to regulators draft new broadband performance policy for Pakistan.

In future work, we plan to benchmark mobile cellular services on achieved data rates. Pakistan is on verge of launching 3G and 4G services [26, 27]. Thus, a performance comparison of fixed broadband with mobile broadband would be interesting and meaningful.

7. REFERENCES

[1] M. Chetty, R. Banks, A. Brush, J. Donner, and R. Grinter, "You're capped: understanding the effects of bandwidth caps on broadband use in the home," in *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems.* ACM, March 2012, pp. 3021–3030.

[2] J. Chen, S. Amershi, A. Dhananjay, and L. Subramanian, "Comparing web interaction models in developing regions," in *Proceedings of the First ACM Symposium on Computing for Development.* ACM, 2010, p. 6.

[3] B. Bilbao-Osorio, S. Dutta, and B. Lanvin, "The global information technology report 2013," *Growth and Jobs in a Hyperconnected World*, 2013.

[4] S. Sundaresan, N. Magharei, N. Feamster, and R. Teixeira, "Characterizing and mitigating web performance bottlenecks in broadband access networks," 2013.

[5] "Federal Communications Commission, 2012 Measuring Broadband America July Report: A Report on Consumer Wireline Broadband Performance in the U.S. FCC's Office of Engineering and Technology and Consumer and Governmental Affairs Bureau, 2012."

[6] "OFCOM, Measuring Mobile Broadband in the U.K.: performance delivered to PCs via dongles/datacards September to December 2010. OFCOM,, 2011."

[7] "OFCOM, U.K. Broadband Performance May 2012: The Performance of Fixed-Line Broadband Delivered to U.K. Residential Consumers. OFCOM, , 2012."

[8] M. Chetty, S. Sundaresan, S. Muckaden, N. Feamster, and E. Calandro, "Measuring broadband performance in south africa," in *Proceedings of the 4th Annual Symposium on Computing for Development.* ACM, 2013, p. 1.

[9] "Pakistan market share," http://www.hamariweb.com/articles/article.aspx?id=37119, [Online; accessed 14-April-2014].

[10] "Internet world states," http://www.internetworldstats.com/asia.htm, [Online; accessed 10-April-2014].

[11] "Internet users in pakistan," http://tribune.com.pk/story/567649/30m-internet-users-in-pakistan-half-on-mobile-report/, [Online; accessed 05-April-2014].

[12] "Broadband policy of pakistan," http://www.isp.com.pk/internet-guides/broadband-policy-by-pta.html, [Online; accessed 20-april-2014].

[13] S. Bauer, D. Clark, and W. Lehr, "Understanding broadband speed measurements," *MITAS project white paper*, 2010.

[14] S. Sundaresan, W. De Donato, N. Feamster, R. Teixeira, S. Crawford, and A. Pescapè, "Measuring home broadband performance," *communications of the acm*, vol. 55, no. 11, pp. 100–109, 2012.

[15] "Ookla," http://www.ookla.com/, [Online; accessed 24-April-2014].

[16] "Akamai," http://www.akamai.com, [Online; accessed 24-April-2014].

[17] I. Canadi, P. Barford, and J. Sommers, "Revisiting broadband performance," in *Proceedings of the 2012 ACM conference on Internet measurement conference.* ACM, 2012, pp. 273–286.

[18] S. Sundaresan, W. De Donato, N. Feamster, R. Teixeira, S. Crawford, and A. Pescapè, "Broadband internet performance: a view from the gateway," in *ACM SIGCOMM Computer Communication Review*, vol. 41, no. 4. ACM, 2011, pp. 134–145.

[19] "Ripe atlas project," https://atlas.ripe.net/, [Online; accessed 24-April-2014].

[20] "Akamai, the state of the internet," http://www.akamai.com/stateoftheinternet/, [Online; accessed 14-April-2014].

[21] "Pakistan net index," http://www.netindex.com/upload/2,21/Pakistan/, [Online; accessed 24-April-2014].

[22] "Welcome to project bismark," http://projectbismark.net/, [Online; accessed 01-April-2014].

[23] I. Grigorik, "Latency: The new web performance bottleneck," *Retrieved April*, vol. 24, p. 2013, 2012.

[24] "Undersea internet cable cut," http://tribune.com.pk/story/527148/undersea-internet-cable-cut-effects-50-of-pakistans-traffic/, [Online; accessed 10-April-2014].

[25] "Bcg e-index score 2013," https://www.icann.org/en/news/presentations/bcg-internet-economy-country-24feb14-en.pdf, [Online; accessed 30-April-2014].

[26] "3g and 4g twin technologies," http://tribune.com.pk/story/702355/3g-and-4g-twin-technologies/, [Online; accessed 04-May-2014].

[27] "Warid set to launch 4g services," http://www.dawn.com/news/1104128/warid-set-to-launch-

4g-services-with-pta-approval, [Online; accessed 04-May-2014].