

Performance Evaluation of Mobile Broadband Cellular Networks in Pakistan

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Abstract—Pakistan is a rapidly growing cellular market with a growth rate of 185 % in number of mobile broadband users during 2014-16 and over 15.75 million mobile broadband users [4]. The exponential increase in broadband penetration demands investigation of mobile broadband performance from an end user perspective. To the best of our knowledge, no extensive study exists to document mobile broadband services experience in Pakistan except a recent Pakistan Telecommunication Authority (PTA) QoS report [8]. This deficiency of evidence is distressing because benchmarking Mobile Wireless broadband performance is primarily important for customers in Pakistan as well as for mobile operators. This will help both mobile operators and regulators to improve and maintain an acceptable level of quality of service. Thus, we conducted a pilot study to benchmark and analyze quality of user experience of mobile wireless users by deployment of an Android application for mobile customers to measure performance of each cellular broadband provider (Ufone, Telenor, Zong, Warid and Mobilink) in Pakistan. We analyzed performance attained at the end user device, quality of service that users are getting and identified performance bottlenecks and possible reasons. On basis of these results, we provide insights to improve mobile broadband internet services (3G and LTE) in Pakistan. Among our list of mobile operators, performance of Zong is the best in 3G networks followed by Mobilink. We consider throughput and latency as core characterizing parameters. Zong 3G has higher sustained throughput, better latency to international servers but in other factors like average signal strength, jitter and last mile latency, Mobilink 3G is superior than Zong 3G. Zong 4G performs better in overall results whereas Warid performs better in last mile latency and jitter. Our results reinforce Pakistan Telecommunication Authority(PTA), QoS survey of 3G/4G for the year 2015.

I. INTRODUCTION

Broadband subscribers have witnessed a sharp rise during past few years as with the advent of 3G/4G in Pakistan [7], considerable growth in total number of mobile broadband (MBB) subscribers is expected [6]. Notwithstanding the increase of broadband connectivity in the state, however, very less is known about the performance of networks. In particular, mobile wireless broadband users have little intelligence about the performance of these networks within the country.

Our previous work [10] has studied the performance of landline and fixed wireless broadband access networks in Pakistan. It has demonstrated some of the plain dissimilarities between connectivity in developed countries and those of less developed regions by providing comparison between them. It also revealed that fixed and fixed wireless providers do not achieve advertised rates, that fixed 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 [10] [14] in the context of mobile wireless broadband service providers in Pakistan. Lack of good performance by mobile broadband service providers, results in decline of it's usage which inturn adversely effect the economy of the country [5]. Thus, In Pakistan neither regulatory authorities have enough data from mobile operators to work on nor they have tools for continuous monitoring for quality of service. Better data is required to inform users about value of their money, and regulators to undertake informed decisions. Our main goal in this effort is to provide a comprehensive overview and tools to access quality of service parameters continuously over time. This paper will look into the following questions;

- Performance comparison of mobile broadband service providers
- Contributing factors to performance degradation
- Consistency of performance and user experience over time

The rest of the paper is structured as follows. In section 2, we provide a literature review and previous works on mobile broadband measurements. Section 3 will look into background of our study and will present methods and methodology used for our measurement. Section 4 will provide insight into results of our study targeting performance evaluation of mobile wireless broadband operators. In section 5, we discuss results and finally conclude with key insights.

II. LITERATURE REVIEW

In [14], Srikanth et al. presented the results from measurements of both fixed and mobile broadband network connections in South Africa by deploying Project BISmark platform. This research focuses on performance comparison of wired versus wireless broadband connections. It missed some broader aspects of cellular networks like the effect of throughput on performance. Yuba Raj et al. [18] measured broadband performance under mobility scenarios. They compared loss and delay in both static and mobile modes. One of the feature considered was to study the effect of user speed on performance using a special test-bed Nornet Edge (NNE). Each device used four UMTS modes. This testbed was used in cars, buses and trains. Speed was hardly more than 60 Km/h.

So effect of high speed was not studied here. Throughput parameter was also not considered. In [12], researchers evaluated mobile wireless broadband performance disseminated detailed information. Measurement data is collected for four service providers on eight devices. Major parameters considered include time, location (California), throughput, jitter, loss, network type, network provider. The study uses Iperf to measure throughput and latency performance. Glasnost tool is used to detect if an ISP is using rate limiting for BitTorrent. Eight testers moved to various places in California and performed tests. Measurement duration was one month. LTE is mainly deployed in urban areas, as a result throughput is significantly less in rural areas. AT&T and Verizon are best in coverage and average throughput. This study lacks diversity and uses Iperf which needs rooted phones resulting in difficulties in penetrating large market. Ferlin et al. [15] analyzed QoS characteristics of mobile broadband networks. Measurement parameters were bandwidth, delay and loss. NNE nodes are connected to five 3G ISPs which were distributed in urban and rural areas. Measurement duration was three months from August to October 2013. Measurements were taken between nodes and the server in Simula research lab. Major findings of the research were; Uplink contributes more to delay whereas Downlink contributes more to loss. Delay in CDMA networks is greater than 3G-UMTS. Some loss packets arrived in bursts, the reason could be a short glitch in network processing. Researchers used small data set with few testing applications and measured performance of only 3G network. A detailed survey on end-to-end mobile network measurement testbeds, services and tools is given in [16]. Measurement capabilities studied in the network include traffic shaping, active measurements, passive measurements, packet content, P2P traffic, ICMP routes, programmable execution, IPv6 use and support for OS platform and network map. Resource usage limits have also been studied for transmission rate, bandwidth cap and port restrictions. The paper argues that network performance criteria are different when taking perspective of a developer, researcher and network operator. Hence, a single performance measurement tool might not be suited in different environments. Through extensive survey, researchers argue that though platforms have matured, but functionality gap with respect to needs of researchers, developers, network operators and regulators still persists. Existing tools are not adequate to capture traffic shaping. Only a few testbeds like Seattle, MITATE, PorotoLan, WindRider and PhoneLab can capture traffic shaping mechanism inside the network while other platforms fail to do so particularly in mobile ISPs. Ashkan et al. [17] have presented a case for network measurement as a service for mobile network. The work addresses several important challenges towards an efficient and practical implementation of network performance. The system, called Mobilyzer is able to isolate several networks in order to provision network performance measurement results. Mobilyzer is a measurement platform with the purpose of standardized measurements in the world. The work of young-Chih et al. [13] characterizes 4G and 3G networks with support

for mobility and multi-path TCP. Since cellular network allows redundant connectivity using multiple wireless paths, data path can allow shifting of traffic from congested and broken paths to higher quality paths that dramatically changes network performance. The experimentation results by Xiao et al. [19] attempt to answer the performance uncertainty in high speed mobility scenarios in cellular networks that run TCP/IP. The study consists of comprehensive measurement of performance for mobile data networks that tend to provide connection to high speed mobile equipment at around 300km/h or even more. Naveed Alam et al. [9] provide a survey of telecommunication services in Pakistan with focus on broadband service providers and their services. Major Service providers included in this study were PTCL, Wateen, World-call, Wi-tribe, Qubee and Mobilink Infinity. The survey also covers various GSM networks along with a brief introduction of mobile broadband (MBB) in Pakistan.

III. BACKGROUND AND METHODOLOGY:

We provide brief background on internet access in Pakistan and present details of measurement methodology followed during the course of our study.

A. Mobile Broadband in Pakistan

Pakistan's mobile penetration has been increasing at a pace immediately after the de-regulation of the sector in 2004 as shown in Figure 1. Mobile penetration has touched 76.6% at the end of 2014 as related to 71.73% in 2013 but decline to a 60.7% in 2015 [7]. The penetration rise in the 2014 is the highest in the last six years showing a new stir in the market with the successful launch of NGMS (next generation mobile services) in the country. During fiscal year 2014-15 because of streamlining the SIM sales and biometric verification of un-verified and un-authorized SIMS, cellular penetration has shown negative growth. This trend is observed because of blocking 26 million active connections under biometric re-verification of SIMs.

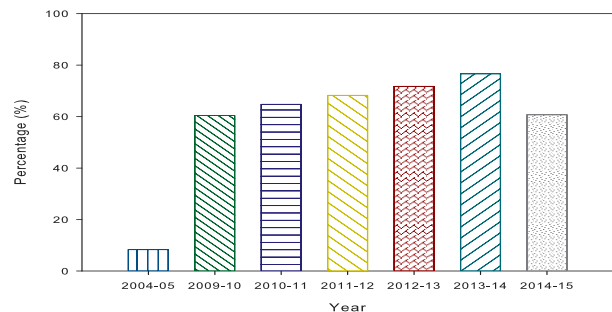


Figure 1. Year wise Penetration rate for cellular networks [7]

Figure 2 shows the broadband distribution among different operators in Pakistan in year 2014 and 2015. In year 2014, there is no mobile broadband ISP player where-as in 2015, most of the market is captured by mobile cellular operators

including Telenor, Mobilink, CMPak (Zong) and Ufone. Thus, according to Pakistan Telecommunication Authority PTA, a rapid increase in mobile broadband is observed, with 0 percent in 2014 to 79.9 percent in 2015 resulting in major portion in broadband market [7].

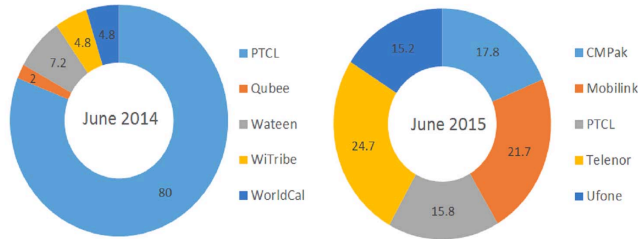


Figure 2. Broadband Operators: Market share [7]

B. Measuring Methods and Approaches:

The aim of this study is to benchmark mobile broadband internet service providers from an end user perspective. Several measures can be used to characterize the performance of broadband networks and to analyze the end user experience. The measurement of end-to-end statistics can provide more useful information than the measurements that are carried out using network parameter assessment within the network. Parameters like delay, connectivity, packet loss and jitter can provide useful information about the quality of the service being provided.

1) *Deployment Scenario:* We developed an android application My Speed Test PK that can take various measurements like latency, throughput, loss and contextual measurements (User android device, network related information like signal strength, local time, battery status, network type, tower id, android version, phone company information etc) from mobile broadband end device. It performs active measurements to identify throughput, latency, loss and jitter. We chose android because application development for android is relatively simple and it does not require special equipment. These devices hold a larger market share as compared to IOS devices [3]. Many device vendors use android operating system. We worked in collaboration with the NOISE lab at Princeton to tailor My Speed Test application [4] according to requirements specific to Pakistan. Our network deployment can be seen in Figure 3. It comprises of one measurement server to conduct measurements and a management server for storing measurements in a database. Mobile devices via an application send measurement data in JSON format to the management server. Server handles JSON by using PHP and stores results in MySQL database. Smartphones communicate with the measurement server for conducting uplink and downlink measurements. Downlink results are calculated at the user end whereas the server sends uplink results back to the mobile device. After results calculation, mobile device shows result to the user and sends them to management server.

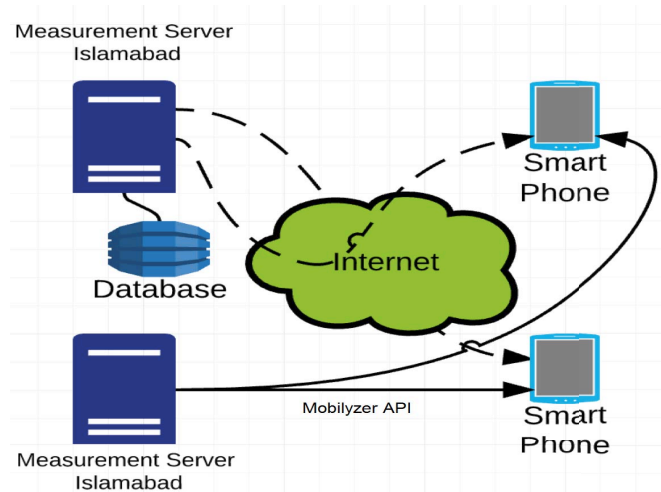


Figure 3. Network Architecture

In order to perform measurements, 102 mobile broadband users registered with various cellular operators from different regions of the country have participated in this study. Volunteers are selected mostly on the basis of personal links consisting of students as well as general public. A balanced mix of users from four big cities Islamabad, Lahore, Karachi and Peshawar are chosen. To ensure that we collect large data-set from these participants, users were funded for mobile internet packages to keep on mobile data as much as possible. Data was collected from these nodes for a period of about two months. Table I gives a detailed view of the number of devices per network along with number of different measurements (throughput, latency, throughput variance, Jitter and Packet loss) taken per operator.

C. Performance Metrics

Following parameters were used to benchmark the mobile cellular operators.

1) *Throughput:* We measure an Uplink and downlink throughput for mobile cellular operators. For uplink speed measurement, client creates a TCP connection with measurement server. Random string of TCP packets are generated and sent to the server for fifteen seconds. In uplink direction, maximum segment size (MSS) for packet is 1358 bytes and in downlink direction, MSS is 2600 bytes. Once this process completes, the server calculates the throughput by dividing received data by total time. In downlink, after establishing a TCP connection, the server sends packets to target device and then device calculates bandwidth by dividing total received data by total time which is fifteen seconds in our case. We have used Mobilyzer API [17] to measure throughput.

2) *Throughput Variance:* After receiving data for 15 seconds, we further divided the data in three equal chunks, and

ISP	Type	Device count	Total Measurements	Throughput	Latency	Packet Loss and Jitter
Mobilink	3G	19	87335	436	85552	1347
Telenor	3G	20	57121	384	55309	1428
Zong	3G	22	152875	570	150382	1923
Zong	4G	10	39044	194	38289	561
Ufone	3G	21	118096	404	116036	1656
Warid	3G	10	37915	181	37206	528
Total		102	492386	2169	482774	7443

Table I
SUMMARY OF MEASUREMENTS

calculate the median of each chunk. We compared median of these chunks against median of original complete data to identify the difference in results. Using this approach we test the impact of shortening in measurements. It is an interesting analysis which in turn can help take shorter measurement duration for future analysis.

3) *Latency*: We found latency to some commonly accessed websites in Pakistan. List of websites is selected on the basis of most accessed websites ranked by Alexa [1]. We pinged commonly accessed servers from Pakistan after every 15 minutes and note down min, max and average round trip time (RTT). Each destination was pinged fifteen times. We used separate thread for every distinct ping destination to perform concurrent execution which will reduce measurement duration.

4) *Loss Rate*: We measured data loss or loss rate by sending 200 ping packets to our measurement server every two hours. Each packet is sent after 500ms. RTT of each packet is note and ratio of lost packets is sent back to the database server. We select local server for loss measurement in order to make sure that the results are not affected by any bottleneck.

5) *Jitter*: To find jitter, we calculate results from same packets that were used to identify loss. We also note down RTT of each packet. We note minimum RTT and find difference of this packet from every arriving packet in a single measurement. We then calculate the average of every jitter value to find average jitter in a single measurement.

6) *Signal Strength*: Signal strength is also note against each measurement. We are interested to find signal strength dispersion in each measurement. Most of our measurements are taken within and adjacent areas of Islamabad, Lahore, Karachi and Peshawar. We measured signal quality and took the average of the signal strength that we got throughout the experiment to find average signal quality.

7) *Measurement Server*: Latency is inversely proportional to sustained throughput [11] [14]. Therefore we deployed a measurement server locally to get more accurate throughput results. Measurement lab provides excellent infrastructure worldwide to measure throughput by using their server but it does not have any server hosted in Pakistan so we deployed our server locally in Islamabad. This server is well equipped and has 50 Mbps bandwidth which is sufficient to serve the purpose. In order to avoid effects of server side limitations on throughput results, we allowed only one measurement at a time from measurement server. Measurement server code is written in Java. It listens for a client to make connection request. After

successful connection, client-server send and receive data for 15 seconds each to measure uplink and downlink throughput.

8) *Contextual Data*:

Along with network quality parameters, we also note down some additional information that can have effects on measurements. It includes information about android device, network related information like signal strength, local time, battery status, network type, tower id, android version, phone company information etc. We named it contextual data. Android API is used to collect this contextual information. Such additional data is helpful in analyzing other factors that effect on network measurement results.

9) *Measurements Frequency*: Table II shows the schedule of measurements taken.

Test	Target	Frequency	Duration
Download Speed	Measurement Server	On User Request	15 sec
Upload Speed	Measurement Server	On User Request	15 sec
Latency	Commonly accessed URLs	Every 15 minutes	15 Ping Packets
Packet Loss	Measurement Server	Every 2 Hours	200 Packets
Jitter	Measurement Server	Every 2 Hours	200 Packets

Table II
MEASUREMENTS FREQUENCY

IV. RESULTS AND DISCUSSION

This section summarizes results of our ongoing study. First, we will examine mobile broadband operators on the basis of latency measurements, then we will look into throughput achieved from operators.

A. *Performance Evaluation Based on Latency Measurements*

This section will give latency measurements on the basis of carrier, variance in latency over time, latency for network type with time, latency during damaged duration of submarine cable, latency by hour to popular websites, latency during static and mobile mode and Latency variance based on signal strength.

1) *Ping Latency by Carrier*: Figure 4 represents latency by carrier type for all 3G/4G networks. The box shows the inter-quartile range of latency values; the line in the box depicts the median value; and the whiskers show 10th and 90th percentiles. In 3G networks, Mobilink and Zong are going neck to neck in median latency values with Mobilink 230.44 ms and Zong 231.539 ms. As far as data set population distribution is concerned, Zong has some outliers very far from normal distribution. Most of distribution of all carriers is similar with only Mobilink having smallest range of variance in latency results. In 4G networks, Zong is leading from Warid. Warid has median results that are comparable to some 3G networks in Pakistan.

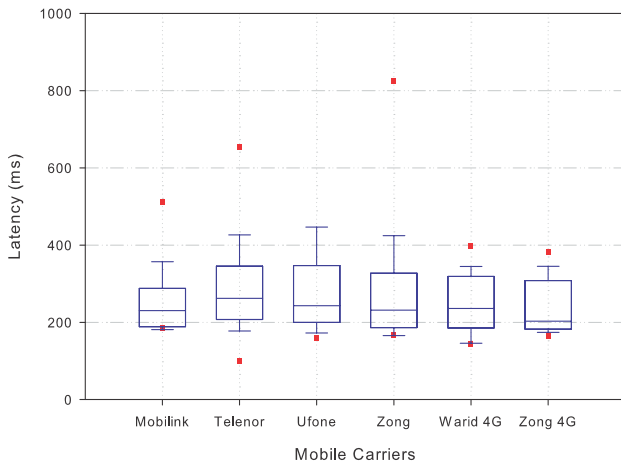


Figure 4. Latency for 3G/4G Networks

2) *Variance in Latency over time*: We examine the variance in latency by pinging Facebook server on per hour basis from different carriers. Figure 5 shows Ufone has higher latencies most of the day till midnight. Mobilink, Warid 4G and Telenor has a fairly stable latency graph with latency start to increase from 7pm to midnight. Zong is at number three in results with peak latencies are very high at night times. Zong 4G is showing excellent latency results throughout the day with little increased latency in peak hours.

3) *Latency for Network Type with Time*: We identified an average latency with respect to network type at every hour of the day. It is observed in Figure 6, LTE presents more stable results throughout the day. Latency values increase only slightly at night. On the other hand, HSPA and HSPA+ tend to fluctuate throughout the day with significant increase from 7pm until just after midnight.

4) *Last Mile Latency*: The last mile is the biggest reason of bottleneck for an end user. We calculated last mile latencies of all networks and shown in Figure 7. Ufone users experience highest last mile latency values. Mobilink network has lowest last mile latency average, which is under 100ms. 4G networks have lowest last mile latencies with Warid has slightly im-

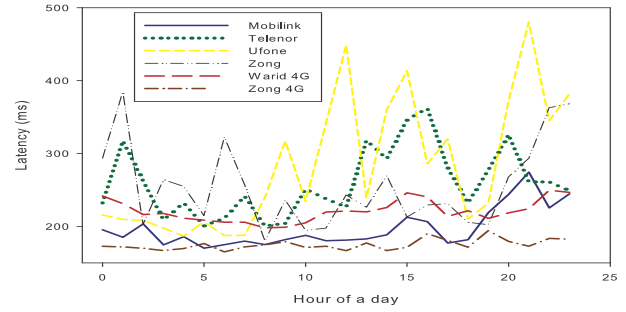


Figure 5. Per hour Latency to Facebook server for 3G/4G Networks

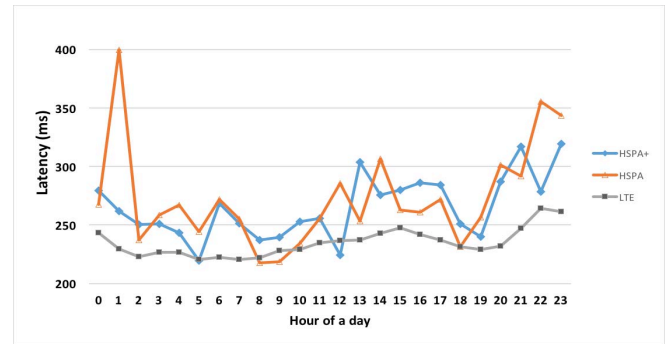


Figure 6. Latency by Network Type

proved results in comparison to Zong 4g.

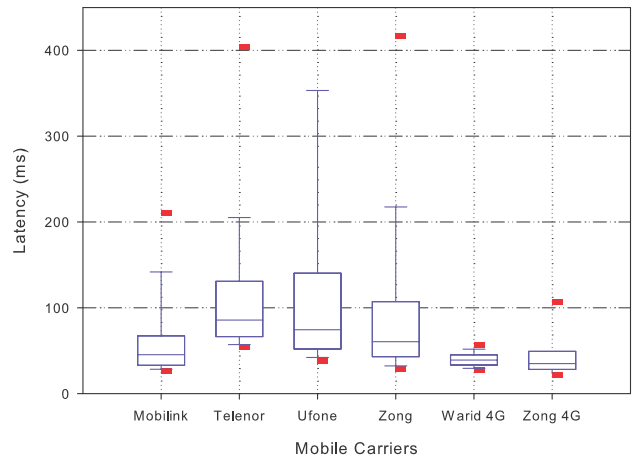


Figure 7. Last Mile Latency of Mobile Broadband Operators

5) *Latency during Cable Damage Period*: On June 24, 2015, Pakistan suffers from internet service due to optic fiber cable disruptions [2]. Figure 8 shows average latencies for duration of more than a month. As it is seen, that most of the results are in magnitude of approximately 200ms-400ms. But

during 24-26 June highest latency values are observed due to cable damage. This was because of damage in two main submarine cables that connect Pakistan to outer world SEA-ME-WE-4 and IMEWE, resulting in higher latency values. However, after recovery of IMEWE cable latency values trend shifted back to normal.

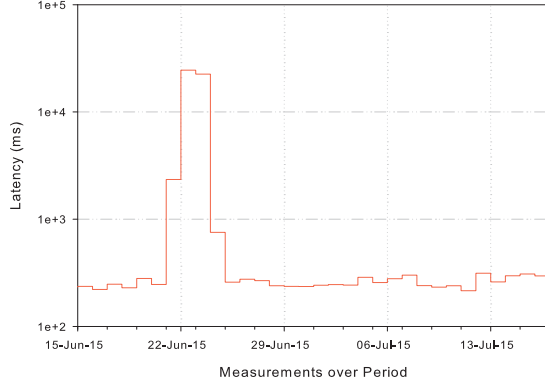


Figure 8. Latency in Cable Damage Duration

6) *Latency to Most visited websites:* Figure 9 gives minimum latency against mostly accessed websites in Pakistan. We also showed latency against our measurement server which is locally deployed in Pakistan. UrduPoint, Facebook and google have lowest latencies from all other international servers. This graph highlights the benefit of local server infrastructure having lowest value for local measurement server. Local server deployment will not only reduce latency, but it will reduce costs as well that incurs due to international traffic approaching from servers.

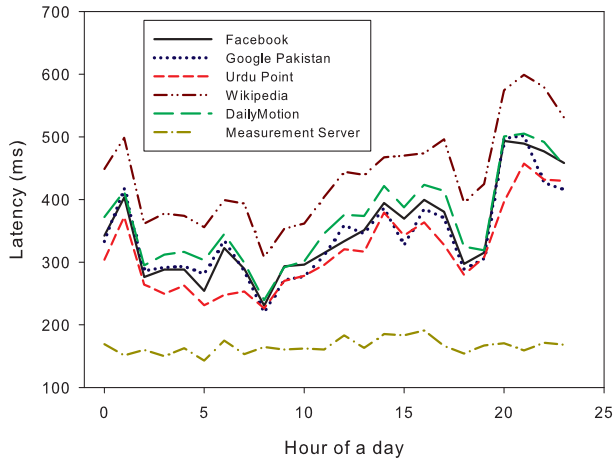


Figure 9. Latency to Popular websites in Pakistan

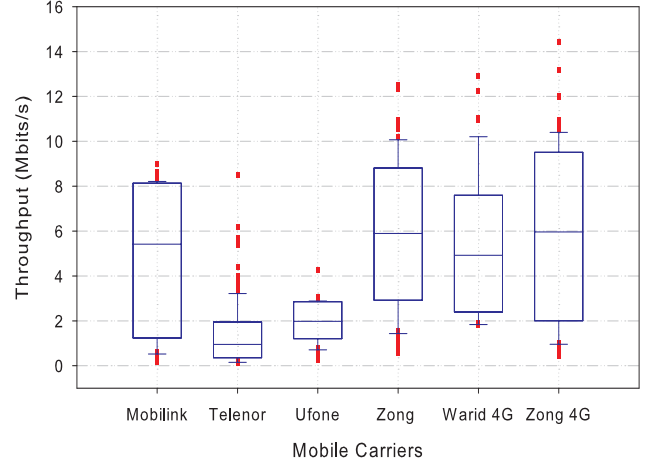


Figure 10. Downlink Throughput to server

B. Performance Evaluation based on Throughput Measurements

This section will benchmark mobile operators based on throughput values.

1) *Downlink Throughput:* Figure 10 shows that among 3G networks, Zong is providing best service with mean of more than 5.8 Mbps which is best, followed by Mobilink with measurement of 5.42 Mbps.. Telenor downlink throughput is poor in comparison with others. Median of Ufone is also below 2 Mbps. These throughput measurements are taken by using a single thread. In case of multiple thread, 4G throughput can be significantly increased as it fills the pipe. However, single thread measurement result gives us fair idea of comparative performance. In these results Zong 4G dominates Warid. Warid results are poorer in comparison to some of 3G networks for single thread.

2) *Throughput Variance in Chunks:* Each throughput measurement, calculates per second data rate for every fifteen seconds. We calculated median throughput for complete duration of fifteen seconds in order to find sustained throughput. Beside this, we are also interested to study the effect of shortening in measurements and for that we divided array of received throughput values in three equal chunks. Then we calculated average of these chunks to identify variance in different chunks. Figure 11 shows that mean throughput of chunks is increasing from chunk 1 to chunk 3.

C. Performance Evaluation Based on Jitter, Packet Loss and Signal Strength

This section gives details of mobile broadband users experiencing jitter and packet loss.

1) *Jitter per Network Type:* Figure 12 shows quite high Jitter values, especially in case of Ufone which has average jitter more than 90ms in case of HSPA and more than 60ms in case of HSPA+. This shows high fluctuation rate in network

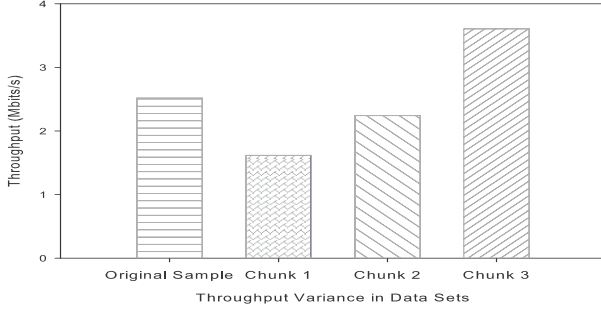


Figure 11. Throughput Variance in Data Chunks

services by Ufone. LTE network is way ahead than other networks with small jitter rate. Jitter of Warid network is very good in comparison to Zong 4G. Telenor and Mobilink are the best networks in respect of Jitter from pool of 3G carriers.

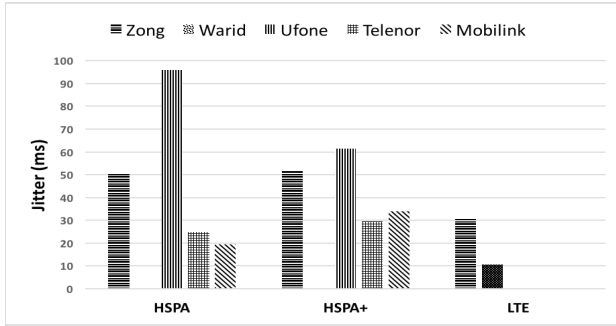


Figure 12. Jitter per Network Carrier

2) *Packet Loss*: Losses cause a significant effect on network quality. Retransmissions adds latency and in case of real time traffic, users experience glitches. Figure 13 shows that all networks have loss values under 2 percent except Telenor which has more than 2% loss ratio.

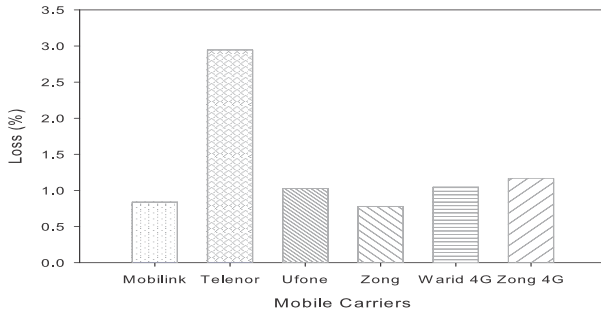


Figure 13. Packet Loss per Carrier

3) *Signal Strength*: Our experiment was conducted largely in major cities where network infrastructure was expected to be

well established. We calculated signal propagation along with other measurements. Overall signal propagation is less than expected. Figure 14 shows, Telenor has least average signal strength of -87 dBm. Mobilink is best with signal strength value which is -72 dBm.

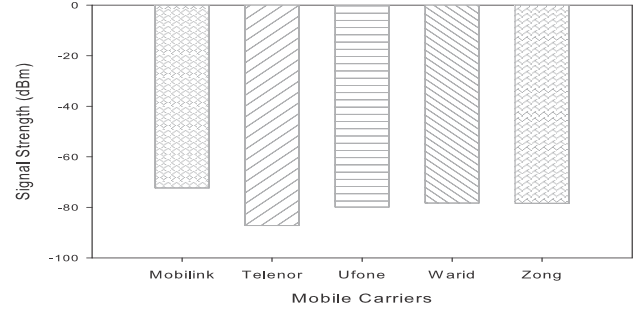


Figure 14. Signal strength of Mobile operators

V. DISCUSSIONS & CONCLUSION

Based on our investigation, we found that number of factors contribute in performance degradation. One of our key findings is that in Pakistan latencies are very high on average. One reason is that servers are geographically far away; even Jang and Urdu Point which are Pakistan based websites also use servers in USA. We also observed some unusual delays in our data-set where latency values ramp up to 40 sec. One possible reason could be excessive buffering of packets (buffer bloat), thus needing more focus in future. In order to over-come this problem, we can reduce buffer size or use scheduler for optimized performance. Last mile latency is an important factor that causes performance degradation [10]. In our findings, Ufone and Zong have more than 200 ms median latencies. Zong 3G and 4G has excellent measurement results in comparison to its competitors however they are ranked last in last mile latency. In comparison, last mile latency values obtained in South African study were under 100ms [14]. By reducing last mile latency and bringing it under 100ms or more would cause significant improvement in mobile network performance.

Another reason for performance degradation is poor signal propagation even in metropolitan cities where operators have well established infrastructure. One of the finding was about local infrastructure in Pakistan. None of mostly used servers such as Youtube, Facebook, Dailymotion are deployed locally. There is also lack of local peering and caching which increases latency. Incentives at government level can help towards improving local infrastructure and local peering.

Thus, looking into the findings, we conclude that 3G/4G structure is in initial stages covering only metropolitan cities. Signals deteriorate more often. Rapid expansion required across country especially for 4G network. Continuous measurements are needed in order to analyze mobile network performance in long run. Support from general public by

using the software and from stake holders by providing the infrastructure like measurement server can help in a great deal. We also conclude that among our list of mobile operators, Performance of Zong is the best in 3G networks followed by Mobilink. Zong 3G has higher sustained throughput, better latency to international servers but in other factors like average signal strength, jitter and last mile latency, Mobilink 3G is superior than Zong 3G. Median latency to international servers and loss percentage are only two parameters where Ufone competes with Mobilink and Zong. Ufone and Telenor do not dominate in any test scenario however in jitter they compete with Mobilink and end up having jitter slightly more than Mobilink. However both these networks are lagging way behind than Zong and Mobilink. Zong 4G performs better in overall results, however Warid performs better in last mile latency and jitter.

In future, we are interested to study the effect of radio resource control (RRC) on measurement results. As there are different states that represent channel acquisition status, thus by finding how data rates effect during transition between different states in HSPA and LTE networks.

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