Service Quality Assessment of Cellular Broadband in Pakistan

By

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Approval

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Abstract

Wireless broadband market is growing in Pakistan. With the introduction of 3G/4G in Pakistani market, a lot of activity is expected to be generated in near future. There is hardly any information available about the performance of these mobile broadband services. Mobile broadband measurements give us insight into the performance of cellular service providers. These measurements provide an assessment whether users are getting what they paid for. Service providers can assess deficiencies and improve their networks. Policy makers can make rules and investment plan in light of such measurements. In this work, we provide a framework to obtain active measurements and store results in management server. We performed a significant analysis to measure performance of each cellular broadband provider 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. Based on these results, we provide insights to improve 3g/4g services in Pakistan.

Chapter 1

1.1. Introduction

In today's world, over 2.6 billion people have smart phones and these numbers are continually increasing. There were 508 million 4G and 1.98 billion 3G users with 2.372 Exabytes of data traffic generated by the end of 2014. In 2020, it is expected that smartphones are going to generate 80 % of data traffic with a figure of 24,852 Exabytes [1]. People are using smart phones for their everyday activities that include video conferencing, chatting, e-mailing, web browsing and streaming. There is a huge number of applications available for smart phones that people download and use. By July 2015, there were more than 1.6 million android applications on google play [2]. In Pakistan, there were 3.79 million broadband subscribers at the end of 2014. Wireless broadband captures 63.1 % of the broadband market share [3]. This ratio is expected to increase in coming years as with the advent of 3G/4G in Pakistan [4], considerable growth in total number of mobile broadband (MBB) subscribers is expected [3].

3G/4G technology is in its initial phase in Pakistan. With the introduction of 3G/4G service, it is important to assess the service quality of this technology. Mobile broadband exposure in Pakistan is complicated in comparison to the developed countries like the US, where there is a well-established infrastructure. Pakistan was provisioned with 3G/4G in 2014 and its deployment is still not fully complete. Its widespread usage and infrastructure dissemination is in process. Some major limiting factors in quick adaptation are:

Broadband access and data rate is costly in comparison to the average income of a person.

Monthly data caps are low in comparison with the wired network.

So ISPs are focusing on the main cities while the focus is slowly moving outside to remote areas. Characterizing QoS (Quality of Service) parameters in early deployment stages of 3G/4G can have significant impact on straightening up gaps in good service provisioning. Measuring mobile broadband is helpful for PTA in the benchmarking process, in which PTA has taken steps [3], [5].

1.2. Motivation

Wireless broadband usage is increasing in Pakistan and it will get boost with the recent arrival of 3G, 4G services. As usage growth is expected, there is a need to assess service quality of cellular broadband providers at end devices. There are two main factors that affect wide level usage. One is cost and the other is performance. Better performance means customer satisfaction which can lead to market share growth for network provider. There is not much independent and open to public 3G/4G measurement data available in Pakistan so we do not know the exact state of QOS. With performance analysis, users will know what they are getting in exchange of cost. Service providers will know deficiencies at their end and make improvements which will result in better service provisioning. As an outcome, end users will observe improved quality of experience. This will eventually lead to market growth and in turn positive effect on the development of the country [6], [7].

Mobile broadband exposure in Pakistan is complicated in comparison to the developed countries like the US, where there is a well-established infrastructure. Pakistan was provisioned with 3G/4G in 2014 and its deployment is still in the initial stage. Its widespread usage and infrastructure dissemination is in process. Some major limiting factors in quick adaptation are:

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1.3. Problem Statement

With immense increase in popularity and usage of smartphones, there is a need for developers as well as service providers to measure the performance of MBB from the end user device. Such information can be helpful for developers and service providers to improve performance and the user's experience. Users can also see performance of different service providers on the basis of QoS measurements like throughput, latency, loss and jitter.

Most of the measurement collection has been done in developed countries like USA. However, there are some differentiating factors like life styles, building structures, population density etc. that can affect results. There is hardly any network measurement data available in Pakistan for cellular broadband. Such a data set cannot only help in benchmarking cellular networks but it can also be a source to set technology on right path by identifying issues at hand. Especially where infrastructure deployment is in the initial stages, room for improvement exists right from the beginning.

1.4. Proposed Solution

We aim to provide a quality of service measurements analysis for cellular broadband usage across 3rd and 4th generation service providers in Pakistan. To the best of our knowledge, this is the first independent study to benchmark 3G/4G technology in Pakistan.

Research contributions

Our contributions are 1) The measurement of cellular broadband performance in static and mobile mode 2) Analysis based on the measurements against a key set of questions:

Performance comparison of broadband providers, contributing factors to performance degradation and the effect of mobility on Quality of Experience (QoE) for end users.

1.5. Thesis Organization

This thesis contains 5 chapters organized into following order.

Chapter 2 contains Introduction to 3G/4G, its architecture and related work.

Chapter 3 consists of design and implementation. In this chapter, we discuss network measurement parameters along with implementation details for these parameters.

Chapter 4 comprises results and discussion of data set collected from several mobile devices.

Chapter 5 consists of conclusion and future work.

Chapter 2
Literature Survey

2.1. Technological Background

When considering broadband networks, Mobile Broadband (MBB) is high speed Internet broadband service designed to broadcast wireless signals to mobile phones, tablets, laptops or any other digital devices in significantly larger geographic coverage utilizing wireless technologies. MBB technologies evolved till date can be classified in different generations among which 2G and 3G had been the most widely used technologies while 4G is also starting to be implemented in various parts of the world while 5G and technologies beyond this are currently in experimental stage [8]. The following is a brief introduction of second, third and fourth generation.

2.1.1. Second Generation

Important technologies in 2G include Global System for Mobile (GSM), General Packet Radio Service (GPRS) and Enhanced Data Rate for GSM Evolution (EDGE). GSM is a Time Division Multiple Access (TDMA) based technology that initially used 25 MHz frequency spectrum in the 900 MHz band, but now also works on the 1800 MHz spectrum band. GPRS and EDGE are considered GSM evolutions to enhance data services as well as to improve Quality of Service (QoS) of 2G MBB wireless networks. IS-95 is also a 2G technology now not very common and used Code Division Multiple Access (CDMA).

2.1.2. Third Generation

Third Generation (3G) MBB network can be broadly divided into 3G UMTS (Universal Mobile Telecommunication Services) and 3G CDMA2000. These technologies are implemented and maintained under the Third Generation

Partnership Project (3GPP). 3GPP has defined the air interface evolution and technical specification for 3G UMTS technologies like WCDMA (Wide band Code Division Multiple Access), HSPA (High Speed Packet Access), HSPA+ (Evolution of HSPA) etc. that fulfills the IMT-2000 (International Telecommunication Union-2000) initially set requirements. The standardized CDMA2000 and CDMA2000 1xEV-DO (Evolution–Data Optimized) are the later stage of the CDMA2000 family standards as defined by 3GPP22 [9],[10].

Initially the UMTS network only used 3GPP release 99 specifications for data and voice services. The 3G UMTS contains number of logical network elements with different functionalities for each. These functionalities are grouped into Core Network (CN) and Radio Access Network (RAN, UMTS Terrestrial RAN-UTRAN). UTRAN is responsible for Radio related functionality whereas CN routs calls and data connections to external network as well as switching. User Equipment (UEs) is an important element of the subsystem of UMTS which interfaces user with its radio interface [11].

In the UMTS, a common core network is used to provide support for multiple radio-access networks like GSM, GPRS, EDGE, WCDMA, HSPA and their evolutions. This provides flexibility to operators for engaging different service to customers in their respective coverage areas. Some examples of UMTS services applications include circuit-switched services, packet-switched services, MMS (Multimedia messaging) and real time video/audio sharing [10].

Wideband Code Division Multiple Access (WCDMA) is Frequency Division Duplex (FDD) mode of UMTS, a popular mode than TD-CDMA (Time Division CDMA) that is Time Division Duplex (TDD) mode of UMTS. In FDD, different radio bands are used to transmit and receive; where as in TDD, both functions on same radio bands in different time-slots alternatively. WCDMA uses direct sequence spread spectrum technique and it is more efficient than GSM. Wideband can translate the available spectrum into high data rates and flexibility to manage multiple traffics like voice, narrowband data as well as wideband data.

3GPP has defined the HSDPA and HSUPA in Release 5 and Release 6 respectively. HSPA supports both HSDPA and HSUPA [12]. HSPA+ is an evolution of HSPA to maximize CDMA-based radio performance initiated in 3GPP Release 7 and continue till Release 11. HSUPA, HSDPA, HSPA and HSPA+ are enhancements in CDMA based systems and studied as connection sub mode of WCDMA.

HSDPA has improved the downlink performance to a very high level. It provides better network performance for packet-data service under loaded conditions, lower latency, greater range of applications with faster application performance and increased productivity. To achieve those features it implements techniques like higher order modulation, high-speed shared channels, short transmission time interval (TTI), fast scheduling, fast link adaption, variable coding and soft combining. On the basis of these features and techniques, HSDPA is able to provide new classes of applications and supports huge number of user's access the network compared to WCDMA release 99.

Similarly, HSUPA enhances uplink performance. It increases throughputs, reduces latency and improves spectral efficiency. To achieve such enhancements, it implements approaches such as enhanced dedicated physical channel (EDCH), short transmission time interval (TTI), fast Node-B based scheduling and fast hybrid ARQ [13]. HSUPA can be used for uplink with or without HSDPA in downlink, mostly together. Similar to HSDPA, HSUPA provides different speed based on number of codes used, TTI value, spreading factors of the codes and transport block size. Combine HSDPA and HSUPA both are called HSPA. In HSPA+, higher modulation techniques are used along with Multiple Input Multiple Output (MIMO) to provide improved bitrates.

2.1.3. Fourth Generation

Mobile WiMAX (WiMAX 2) and LTE (Long Term Evolution) [11] are the examples of Fourth Generation (4G) technologies which have been fully realized as Mobile broadband. Advanced LTE which is an improvement from LTE is known as true 4G. HSPA+ and WiMAX 1 are considered as pre-4G technologies. LTE has been favored more over WiMAX over the years due to various performance improvements. LTE (Long Term Evolution) is the most important evolution of 3G defined by 3GPP which can operate in new and more complex spectrum without backward compatibility with WCDMA where as HSPA needs to consider backward compatibility. In normal implementations, HSPA doesn't include all the technologies that LTE uses, however the installed base of equipment can be changed to accommodate new features while serving previous terminals as well, thus being cost-effective. Though LTE is free from the previously used terminal specifications thus is not restricted by older designs, and is also optimized for IP transmission.

LTE is based on IP protocol. Voice and data is served by following IP protocol. When mobile switches on, an IP address is allocated and it is de allocated only when it switches off. Access network is based on OFDMA (Orthogonal Frequency Division Multiple Access), improved modulation and multiplexing. Downlink data rate can be up to 300Mbps. Table 2 briefs the uplink and downlink data rate of major 3G and 4G technologies that are used in Pakistan.

Table 1 MBB generations with related standards and features

Generation	Features	Standard
2nd Generation (2G)	14.4 Kbps digital, voice and short text	TDMA, GSM, CDMA, IS-95, IS-136
2nd Generation (2.5G)	Up to 48 Kbps packetized and digital, voice, data, email, web browsing	GPRS, EDGE
3rd Generation (3G)	144 Kbps to 2 Mbps digital and broadband, voice, data, video, MMS	IMT 2000, CDMA 2000 (Ev-DO), (EGPRS) EDGE, UMTS, FDMA, TD-SCDMA
3rd Generation (3.5G)	3.56-42 Mbps digital and broadband, voice, data and video.	HSPA, HSPA+
4th Generation (4G)	100 Mbps – 1 Gbps digital, broadband and IP Network, voice, data, video, interconnectivity, lower costs	WiMAX, WIBRO, LTE

Table 2 Theoretical Bandwidth of 3G and 4G networks in Pakistan

Technology	Downlink	Uplink	Remarks
LTE (4G)	100 Mbps 150 Mbps 300 Mbps	50 Mbps Cat1/2 75 Mbps Cat 3	LTE with data rate up to 150 Mbps is deployed in Pakistan
HSPA (3G)	14.4 Mbps 21 Mbps	5.76 Mbps 5.8 Mbps	
HSPA+ (3G)	42 Mbps	11.5 Mbps	HSPA+ is deployed in Pakistan.

2.1.4. Mobility Support

The 3GPP standard for E-UTRAN [14] mandates that the system provide support for mobility throughout the entire cellular infrastructure. The mobility support should be further optimized to cater for low speed from 0-15km/h as well. Higher speed between 15-120 km/h need to intelligently handled so that performance does not degrade much. Further, the standard provides guidance that the network performance should not degrade or not be much compromised when a mobile device travels with speeds ranging from 120km/h to 350km/h or even up to 500km/h if a supporting frequency band is available. Real time traffic and voice services support at high speed by the system shall be maintained at E-UTRAN and continue till UTRAN, providing guaranteed bit rate traffic flow for all concerning speed levels and with minimum quality disruption or interruption time. Though the speeds of 250km/h are not expected to be by majority of the system users, but still under special case, such a high speed case can be met at any time. Hence the system must deal it as a special scenario and provide mobility solutions concerning the channel conditions.

2.2. Mobile Network Infrastructure in Pakistan

Telecommunication sector in Pakistan was deregulated in 2004 [15],[3] subsequently private companies were also given licenses to operate. This deregulation started a new broadband era in Pakistan where new telecommunication companies emerged and contributed to significant growth. Following is the list of mobile operators that are offering mobile broadband in Pakistan.

Table 3 Mobile Carriers

Operators	Technology		Data Rate (Mbps)
	Mode	Sub-Mode	
Mobilink	3G	HSPA+	Up to 42Mbps
Telenor	3G	HSPA+	Up to 42Mbps
Zong	3G	HSPA+	Up to 42Mbps
	4G	LTE	Up to 150Mbps
Ufone	3G	HSPA+	Up to 42Mbps
Warid	4G	LTE,	Up to 150Mbps

All 3G and 4G networks except Warid also support HSPA+, HSPA, UMTS, EDGE and GPRS. Warid is 4G and 2G only which means it supports LTE, EDGE and GPRS only.

PTA published annual report for 2014 [3] for broadband and cellular networks. This report also includes information about broadband penetration, number of subscribers and market share of telecommunication companies. Statistics derived from this report can be seen in figure 1, 2, 3 and table 2.

Pakistan's mobile penetration has been increasing at a surprising pace immediately after the de-regulation of the sector in 2004. Mobile penetration has touched 76.6% at the end of 2014 as related to 71.73% in 2013. 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.

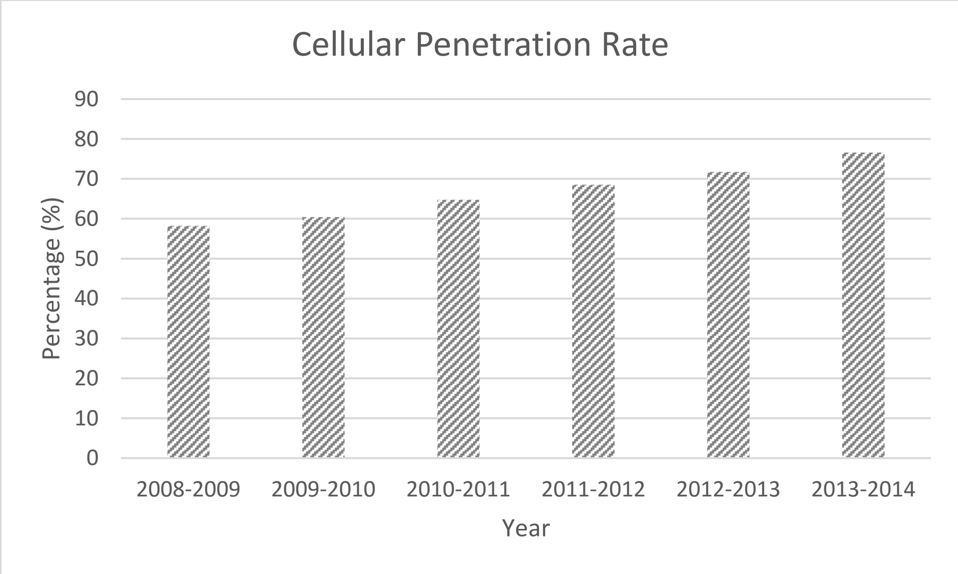

Figure 1 Year wise Penetration rate for cellular networks (Source: PTA Annual Report 2014).

Cellular mobile subscribers in Pakistan reached 139.9 million at the end of June 2014 compared to 128.25 million as of end June 2013, showing growth of 9.1% as compared to 6.7% during the parallel period last year. Progress in this part is a healthy indication for the cellular operators as more subscribers mean chances for revenue production.

Table 4 Cellular Subscribers (No of active SIMS) (Source: PTA Annual Report 2014).

S.No	Years	No Of Active SIMS (Millions)
1	2007-2008	88.0
2	2008-2009	94.3
3	2009-2010	99.2
4	2010-2011	108.89
5	2011-2012	120.15
6	2012-2013	128.25
7	2013-2014	139.90

Cellular mobile operators added 11.04 million net new subscribers during the 2014 in comparison to 8.8 million during the parallel period last year 2013.

Following figure shows the trend of net additions during the last four years (2010-2014) of all cellular mobile companies in Pakistan. It is apparent that Zong has been the fastest increasing operator in Pakistan and the company succeeded to add the maximum number of additions (6,152,729) this year as well.

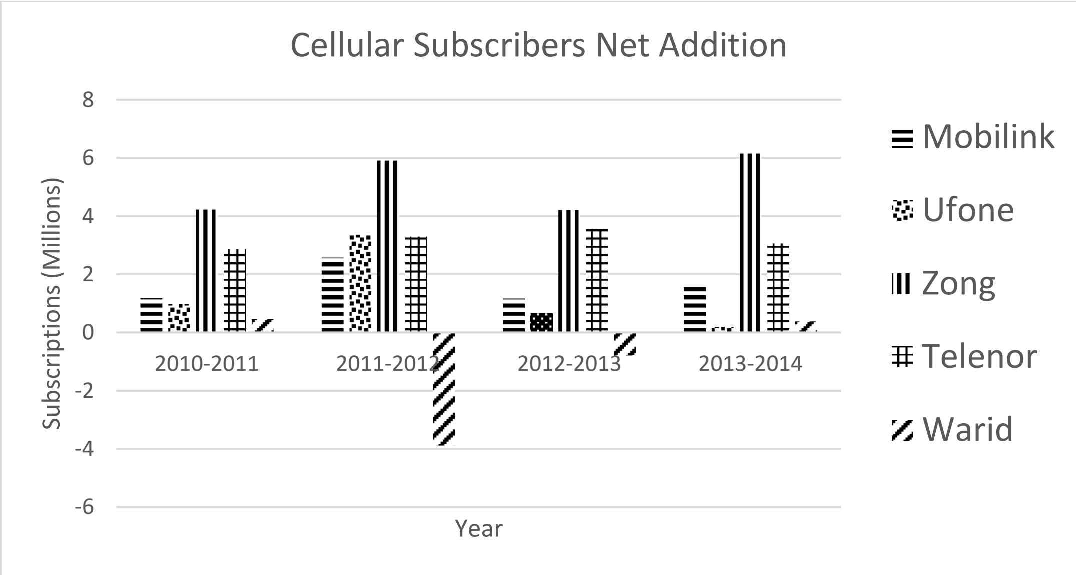

Figure 2 Net addition in cellular subscribers for each network (Source: PTA Annual Report 2014).

According to this report, Mobilink holds the highest share in market which is 27.7% followed by Telenor's 26.1%. Although Zong has 19.4% of market share but its annual net addition for subscribers is highest in last four years as shown in figure 2. Warid has left with under 10% of market share, however it observed addition in net subscribers for year 2014 in contrary to year 2012 and 2013 where it observed lost net subscribers. Ufone has market share of 17.4 %. It is expected that 3G/4G services can play important role in changing this scenario. So good service provisioning in mobile broadband can play significant role in improving the market share of a mobile carrier.

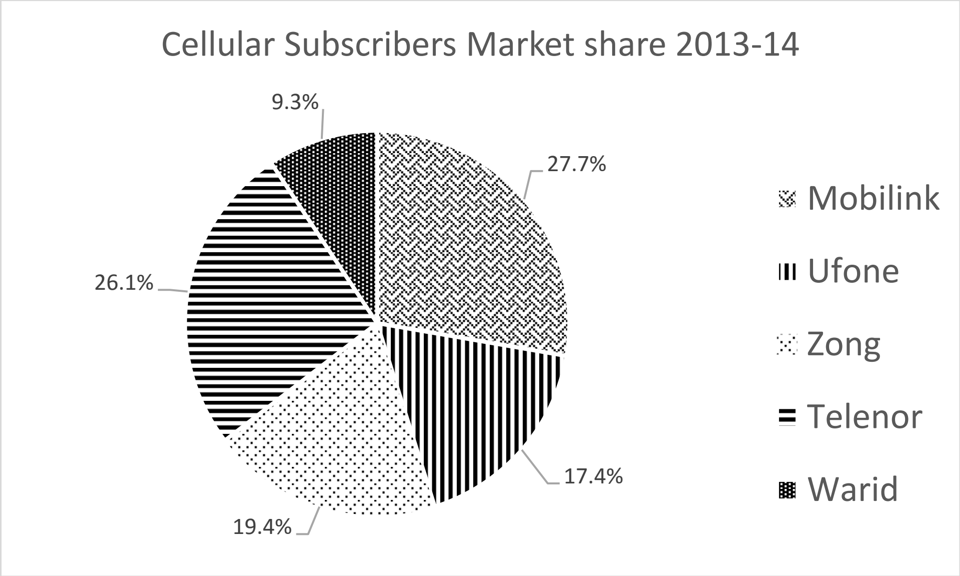

Figure 3 Market Share of each mobile network based on total subscribers (Source: PTA Annual Report 2014).

Broadband penetration in Pakistan is only 2.7 %, while mobile penetration is 76.6 % [3]. It is expected that introduction of mobile broadband where people will be able to access internet on smartphones by using 3G/4G will result in a significant increase in broadband penetration.

2.3. Related Work

In this research [16], Srikanth et al. presented the results from measurements of both fixed and mobile broadband network connections in South Africa are presented. According to the results, it is concluded that customers of both fixed and mobile broadband connections do not get the advertised speed. However, mobile users get relatively higher throughput than fixed broadband. High latencies to the destinations plays a vital role in determining the consistency in the performance that the users get. This research was limited to find the following measurements. Whether users achieve speeds which are advertised by the ISPs or not. Speed comparison of fixed line broadband and Mobile broadband connections. Performance measurements to commonly accessed websites from both types of connections. Also elicitation of the reasons because of which performance suffers was part of the scope. The researchers deployed routers in South Africa across 15 ISPs. They took three months measurements using two 3G dongle devices. An android application was developed and installed on hundreds of android devices for collecting the mobile performance, which users actually get at different times and locations. Five months measurements were collected using the android application. Throughput measurements were taken on demand by the user. It was observed that throughput achieved is less than advertised by the ISP (contrast to the measurements which were taken in UK/USA). Also interestingly, throughput of mobile broadband was higher than the fixed broadband. Latency and meta-data was collected automatically after a fixed time interval. Latencies are variable. Some ISPs have more latency than others. In general, latencies are higher for mobile in comparison to fixed broadband. Enriched dataset with measurements by using mybroadband tool. This research focuses on performance comparison of wired versus wireless broadband connections. It missed some broader aspects of cellular networks like the effect of speed on performance.

In this research [17], Yuba Raj et al. measured broadband performance under mobility scenarios. They compared loss and delay in both static and mobile modes. One of the feature was to study the effect of speed on performance. They used a special test bed Nornet Edge (NNE). NNE is a special embedded system with the Linux distribution. Each device used four UMTS modes. This testbed was used in cars, buses and trains. Data was collected for four months and four network operators were used to take measurements.

Connectivity, latency, packet loss were main measurement parameters. They compared the performance of different network operators under mobility and studied the impact of speed on loss and delay. Slight effect was noted under mobility. The results did not indicate any significant deterioration. However speed was hardly more than 60 Km/h. So effect of high speed was not studied here. Throughput parameter was also not considered.

In [18], researchers measured and evaluated mobile wireless broadband performance and disseminated detailed information to people. Measurement data is collected for four service providers on eight devices. Major parameters are time, location, throughput, jitter, loss, network type, network provider. It used 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 at 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. Results lack diversity. Used Iperf which needs rooted phones. Difficult to penetrate large market due to rooted phones.

Ferlin et al. [19] analyzed QOS characteristics of mobile broadband networks. Measurement parameters were bandwidth, delay and loss. NNE nodes are connected to five 3G ISPs which are 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 are discussed subsequently. 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 [20]. 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 the network performance criteria are different when taking the perspective of a developer, researcher and network operator. So a single performance measurement tool might not be suited in a different environment. Through extensive survey, researchers provide the argument that though platforms have matured, but functionality gap with respect to the needs of the 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. After traffic shaping, churn is considered an important factor that is inherent in platforms that are particularly used for ad hoc user participation. This means that such tools are not suited for long term network performance measuring instances. Though a number of testbeds may enable developers to prototype the network performance before they actually deploy the system, this however provides disparity as to how they present functionality in terms of APIs and models. Other issues include selective network diagnostics, exchange of P2P traffic, ICMP traceroutes, NAT traversal, and device selection criteria using API flexibility. Another important concern is the relative accuracy inherent is the variety of platforms and their measurement criteria. The different measurement criteria for relatively standard network metrics such as throughput jitter and delay makes accuracy measurement difficult. Finally the work outlines important tests necessary for determining the suitability of a network device, service or a platform. These tests include uplink and downlink throughputs, latency, signal coverage, successful probes, webpage load time, multimedia support, supper for mobile OS platform and hardware specifications.

Ashkan et al. have presented a case for network measurement as a service for mobile network [21]. The work addresses several important challenges towards an efficient and practical implementation of network performance requirement. The system, called Mobilyzer is able to isolate several networks in order to provision network performance measurement results. Secondly, the contextual information ensures proper interpretation of results and task scheduling. The system is further able to maintain globally coordinated view of resources for distributed and dynamic experiments. The system allows distribution of Mobilyzer as a library for applications thus provisioning an incentive and low barrier to adoption that is considered a necessity for large scale deployments. The measurement types supported by the system include basic DNS lookups, ping, traceroute, TCP throughput, UDP burst and HTTP GET. Composed sequential and parallel measurements are also supported. In addition, complex RCC timer interface, Video

QoE and page load time can also be measured. The efficiency of the system is evaluated with development experience, measurement isolation, scheduling delay, power usage, data usage, CDN redirection effectiveness, network diagnostics and page load time. With promising results, the service type platform is a development incentive for further applications to come in future with intense broadband network requirements.

The work of young-Chih et al. [22] 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 the network performance. When examining 3G and 4G networks with WiFi, there exists a possibility for both single-path and multi-path data transport. The paper in this perspective performs measurement of single path transport using TCP over 4G and 3G. The traffic is then characterized by throughput, packet loss and the round trip time. The authors also evaluated the transport using multipath TCP in a cellular environment and showed that in ever changing environments; path diversity can provide more reliable and efficient TCP transfer. Results suggest that 4G performs better against WiFi and 3G when taking into account the loss rate and throughput. In a high bandwidth environment, the 4G network controls the rate at which the data is transferred to the receiver which may sometimes result in buildup of queues. The authors suggest that in such queue buildup scenarios, the default TCP's settings that cache senders slow-start threshold should be removed since it cutoffs the newly opened flows slow-start value. Further, by properly assigning a buffer of socket to each flow in the 4G network, flows can achieve higher throughout separately. If such issues are not catered, they affect the performance of single as well as of multi-path TCP connection. Through experimentations, it is shown that the multi-path TCP can support mobility without any compromise of connections, which ultimately leads to dynamic offloading of traffic to paths with different channel diversity. To add up with the results, it is conceded that the exponential timeout scheme is not exact for Wi-Fi links, which should rather be adjusted since hotpots in moving vehicles do not last longer than 2 minutes. Hence the authors suggest use of a scheme wherein bad paths can be detected and removed quickly resulting packet exchange at the first connection. Some other important concerns in this regard include the negative impact of split connection to multi-path TCP and the operator connection time out policies.

The experimentation results by Xiao et al. [23] attempts to answer the performance uncertainty in high speed mobility scenarios in cellular networks that run TCP/IP. The study consists of comprehensive measurement of the performance of mobile data networks that tend to provide connection to high speed mobile equipment at around 300km/h or even more. Such speeds are now becoming a common place in most of the high speed mass transit systems. As far as performance of TCP over LTE networks is concerned, it is observed that decent throughput exists with even slightly high speed mobility. This however is different when comparing to driving at 100km/h and stationary scenarios, where the RTT value is much better and with lower variance than in high speed mobility. The main concerning issues for lower performance in high speed mobility scenario include handoffs and wireless channel condition itself. These two factors greatly affect the performance as well as the performance of the higher level protocols.

Faheem Awan et al. [24] presented a comparative study of broadband performance in Pakistan against previous researches like [16]. Researchers emphasized on the need of independent measurement study in Pakistan where broadband internet is rapidly increasing. Measurement parameters include throughput, latency, jitter and shape rate. Fifteen Bismark routers were deployed in Islamabad, Rawalpindi, Wah and northern Pakistan. Most of the results complied with previous measurement studies. It was observed that users are not getting advertised speed, latency contributes more to poor performance than throughput, wireless broadband like Evo has a higher throughput in comparison to wired broadband.

Naveed Alam et al. [25] provides a survey of telecommunication services in Pakistan. Researchers discussed various broadband service providers and their services. Major Service providers are PTCL, Wateen, World-call, Wi-tribe, Qubee and Mobilink Infinity. This research also focused on various GSM networks along with a brief introduction of MBB in Pakistan. Although Pakistan is fast growing telecom industry yet researchers emphasized to increase research and development in Pakistan telecom industry which can lead towards economic development.

Chapter 3
Design and Implementation

Assessing service quality of wireless broadband providers is more complicated than fixed line broadband. Careful consideration is needed to standardize measurement parameters. Throughput testing needs to be done time and again in order to get accurate results. On the other hand, high data transfer rate and data caps prevent from excessive testing parameters. So finding right set of parameters is necessary that can rightly access service quality. For mobile applications, it is necessary that we also note down context of that measurement e.g. location of mobile, battery status, signal and service providers. These are some examples that we need to cater.

It is necessary for service providers to keep check on performance achieved by users. This is an important aspect in today's competitive environment. If service providers can know the parameters from an end user device that affect quality of service, they can improve their services to provide better satisfaction level to the customer and hence it can improve their market share.

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. Statistics like delay, connectivity, packet loss and jitter can provide useful information about the quality of the service being provided. Connectivity can be measured as consecutive number of packets received without loss. Latency is defined by the sum of several kinds of delay occurred while processing and transmitting network packets. In latency measurement, RTT (Round Trip Time) defined an important performance component. Packet loss in broad band networks particularly wireless networks may occur due to the congestions, transmission errors over the air interfaces, handover in mobility and insufficient buffers at end points.

In order to measure service quality of wireless broadband, we developed an application that can take various measurements like latency, throughput, loss and contextual measurements. We used a measurement server to take different measurements from and saved results on the management server. Analysis of these measurements gave us an idea of wireless and cellular service quality in Pakistan.

3.1. Architecture

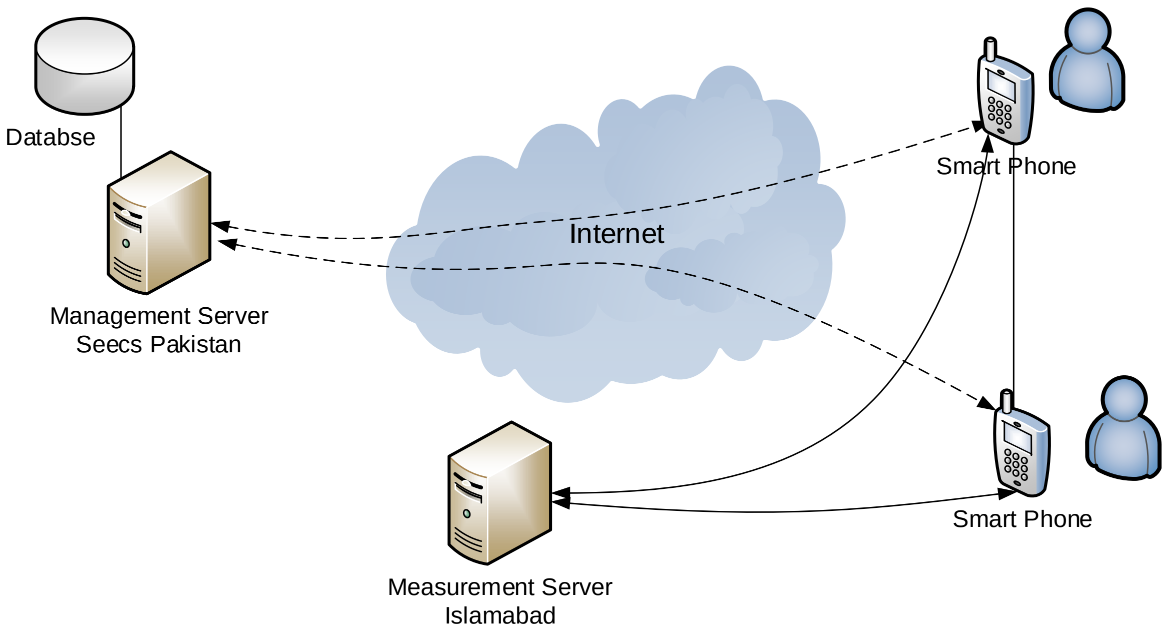

Figure 4 Measurement Architecture

We deployed one measurement server and one management server to conduct our measurements. Management server serves the purpose of storing measurement results in database. Mobile devices send measurement data in JSON format to the management server. Server handles JSON by using PhP and stores result in MySQL database. Measurement collection duration is two months and 102 devices participated in the study. Detail of number of devices per network is given in table 7.

Smartphones communicate with the measurement server for conducting uplink and downlink measurements. The server sends uplink results back to the mobile device.

Downlink result is calculated at the device end. After result calculation, mobile device shows result to user and sends it to management server.

3.2. Design

We designed an android application to collect measurements from mobile broadband. 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 [26]. Many device vendors use android operating system. So by using this, we can have rich data set.

There are two types of android phones that are rooted and non-rooted. Rooted phones have user access to the kernel and as a result these can access detailed measurement parameters like packet level details. But only a few users have rooted phones and most of such phones are used either in a research group or institute. So for the sake of the richness of data set, we performed measurements on non-rooted devices.

We worked in collaboration with the NOISE lab to tailor My Speed Test application [27] according to requirements specific to Pakistan and renamed it as MY Speed Test PK which is also available on google application store [28].

My Speed Test is the network measurement software intended to measure service quality on mobile devices. It performs active measurements to identify throughput, latency, loss and jitter.

3.3. Testing Parameters

Following are testing parameters that we used:

3.3.1. Throughput

Uplink and downlink throughput are measured. For uplink speed measurement, client creates a TCP connection with measurement server. Random string of TCP packets is generated and sent to 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 with total time. In downlink, after establishing a TCP connection, the server sends packets to target device and that device calculates bandwidth by dividing total received data with total time which is fifteen seconds here. We used Mobilyzer API [20] to measure throughput. Which is introduced by researchers at the University of Michigan and Northeastern University to measure network quality. It provides common service for all researchers and developers to prepare measurement applications using this API. This API can result in global coordinated measurements that will improve consistency and efficiency.

Throughput Variance

After receiving data for 15 seconds, we further divided the data in three equal chunks, and calculated the median of each chunk. We compared median of these chunks against median of original complete data to identify the difference in results. In this way, we tested the impact of shortening measurements. It was an interesting analysis which in turn can help to take shorter measurement duration in future analysis.

3.3.2. 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 [29]. In Pakistan, there is a very poor infrastructure for local servers hosting. So no famous sites have servers deployed locally.

We pinged commonly accessed servers in Pakistan after every 15 minutes and noted 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. This test is conducted after every 15 minutes.

Table 5 Top visited Websites in Paksitan

Sr. No	Name	Address	Location
1	Urdu Point	www.urdupoint.com	USA
2	Jang	Jang.com.pk	USA
3	Google PK	www.google.com.pk	USA
4	OLX PK	www.olx.com.pk	USA
5	Google	www.google.com	USA
6	Facebook	www.facebook.com	USA
7	Twitter	www.twitter.com	USA
8	Dailymotion	www.dailymotion.com	France

3.3.3. Loss Rate

Loss is another factor that effects on performance of the network. Reliable and timely delivery of data is critical, especially in live streaming and voice over IP. In case of TCP traffic, minimal data loss can help in less frequent retransmissions which can improve service quality. We measured data loss by sending 200 ping packets to our measurement server every two hours. Each packet is sent after 500ms. RTT of each packet is noted and ratio of lost packets is sent back to the database server. Reason behind selection of local server for the measurement of loss is to make sure that the results are not affected by any bottleneck which is not local to Pakistan. However in case of latency, we are also interested in finding time to reach commonly accessed websites.

3.3.4. Jitter

Jitter shows variation in latency. When jitter increases a lot, even higher bandwidth connection becomes an obstacle in achieving required quality. Jitter effects live streaming and voice over IP category of applications. A stable connection with minimum jitter rate is preferred by users. To find jitter, we calculated results from same packets that were used to identify loss. We also noted down RTT of each packet. We noted minimum RTT and find difference of this packet from every arriving packet in a single measurement. We then calculated the average of every jitter value to find average jitter in a single measurement.

3.3.5. Contextual Data

Along with network quality parameters, we also noted 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. Detail of complete contextual data that we collected with each measurement is available in Annex.

3.3.6. Signal Strength

Signal strength is also noted 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.

3.3.7. Measurement Server

Latency is inversely proportional to sustained throughput [16][30]. So 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 there was geographical constraint involved in it 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. To be on the safe side and to ensure throughput result does not effect from server side limitation, 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.

3.3.8. Mobility

We also kept track of person's movement when possible during measurement collection and studied its impact on network performance. We used GPS for movement speed anticipation along with other measurements. We encouraged users to keep GPS on as much as possible especially during travel. To further support our cause, we funded users to purchase mobile internet packages. With other measurements, our application also monitors latitude, longitude, altitude and speed. We are particularly interested in comparison of data in static and traveling scenarios. We divided traveling speed in three categories.

Table 6 Mobility Categories

Category1	Category2	Category3
>0-15	>15-60	>60-120

3.4. Test Schedule

Throughput:

Throughput test runs on manual request from the user. It runs for fifteen seconds in downlink direction and fifteen seconds in the uplink direction.

Jitter:

Jitter test is conducted after every two hours.

Loss test:

This test also started after every two hours.

Latency test:

Latency measurements start after every fifteen minutes.

Table 7 Testing Schedule

Test	Target	Frequency	Duration
Download Speed	Measurement server	On user request	15 seconds
Upload Speed	Measurement server	On user request	15 seconds
Latency	Commonly accessed websites	15 ping packets Every 15 Minutes	
Packet Loss	Measurement server	200 Packets Every 2 hours	
Jitter	Measurement server	200 Packets Every 2 hours	

Chapter 4
Experimental Results and Evaluation

Table 7 represents a summary of the total number of collected measurements which are approximately 0.5 million in total. The table also shows the distribution of devices on the basis of mobile networks that participated in the study.

Table 8 Summary of Measurements

ISP	Type	No of Devices	Total	Throughput (Mbps)	Latency (ms)	Packet Loss & Jitter (ms)
Mobilink	3G	19	87335	436	85552	1347
Telenor	3G	20	57121	384	55309	1428
Zong	3G	22	152875	570	150382	1923
	4G	10	39044	194	38289	561
Ufone	3G	21	118096	404	116036	1656
Warid	4G	10	37915	181	37206	528
Total		**102**	**492386**	**2169**	**482774**	**7443**

We displayed results by using bar charts, line graphs and box plots. Bar charts show a comparison of mean values between different data categories. Line graph presents results that track changes over a period of time. By using line graph, we can find relationship between two data sets. Box plot displays the distribution of numerical data through quartiles. Bottom of box is first quartile and top is third quartile. Bar inside the box is first quartile which is median value. Whiskers outside the box show minimum and maximum value. For minimum value, we took 5th percentile and for maximum value, we took 95th percentile. Spacing between quartiles of box plot reflects skewness and dispersion of the data.

Pakistan has an internet connection with the world through four submarine cables which are South East Asia-Middle East-West Europe 4 (SEA-ME-WE-4), South

East Asia-Middle East-West Europe 3 (SEA-ME-WE-3), India-Middle East-Western Europe (IMEWE) and Transworld (TW1) [24], [31]. Fault in submarine cable SEA-ME-WE-4 was observed near Karachi on 24th June. Pakistan Telecommunication Company Limited (PTCL) lost 178 Gbps as a result. Meanwhile addressing the fault, load was also shifted on other main submarine cable IMEWE. On 25th June, IMEWE cable also suffered from damage which choked its bandwidth. Another 110 Gbps was lost as a result of this cable damage. Pakistan was left with only 72Gbps during that time. On June 26, IMEWE submarine bandwidth was restored [32] while SEA-ME-WE-4 was fully repaired on July 17 [33]. We also studied the effect of cable damages during our measurements.

4.1. Latency

4.1.1. Ping Latency by Carrier

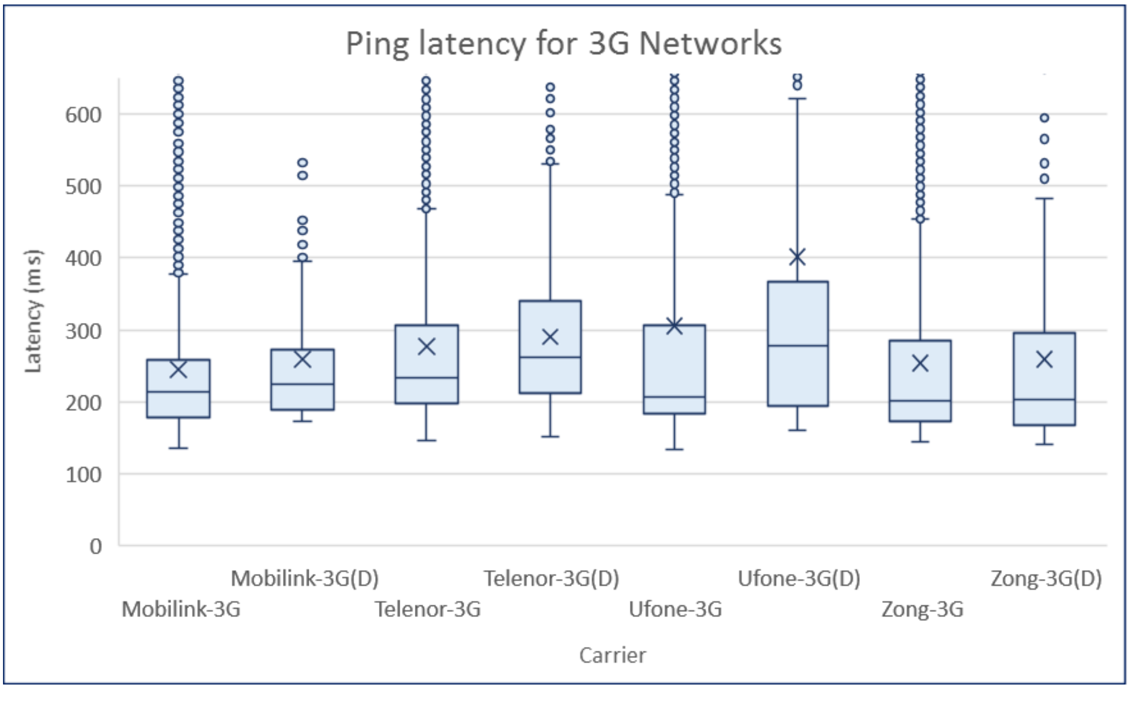

Figure 5 Box Plot of Ping Latency for 3G network Carriers. D represents measurements collected in cable damage duration.

This box plot represents latency by carrier type for all 3G networks. Carrier name followed by (D), Mobilink-3G (D) for example, shows results from measurement collection in cable damage duration whereas other observations depict measurements that are collected throughout the study period. Zong has lowest median latency followed by Ufone. However its mean latency result is worst in comparison to other networks. Mobilink mean result is best among all networks and its median result is touching the tail of Zong and Ufone. Overall median latency results do not differ among all service providers. However, mean results vary, especially Ufone has a worst mean value which shows that there are some higher latency results in Ufone that are degrading overall mean result. As far as data set population distribution is concerned, most of the values of Ufone lie under 200ms resulting in smaller median result than Telenor and Mobilink network. In cable damage duration, all networks suffered from congestion due to bottlenecks at gateways.

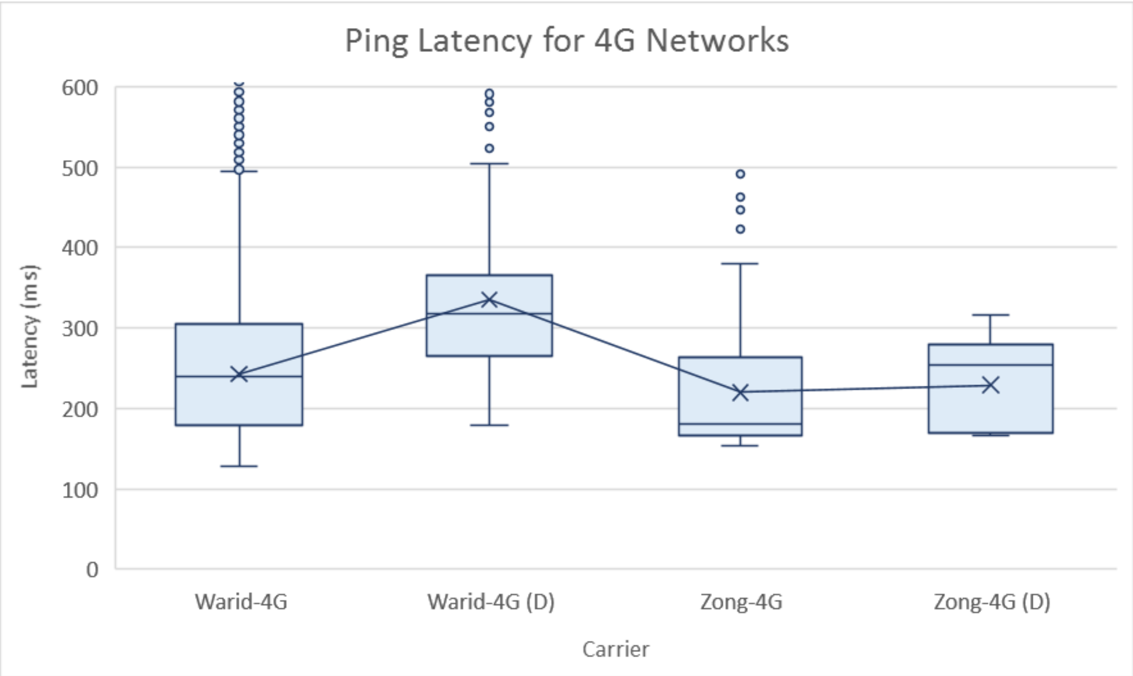

Figure 6 Box Plot of Ping Latency for 4G network Carriers

Zong has lower latency results in 4G networks as well. Median and mean latency for Zong is better than Warid in both normal and cable damage periods. In cable damage period, Warid median latency increased 75ms while Zong experienced 74ms increment in median latency.

4.1.2. Latency by Carrier with Time

Here we identified per hour latency on basis of carriers. Ufone has higher latencies in daytime as well along with night hours. Mobilink and Warid has a fairly stable latency graph with latency start to increases from 7pm to midnight. Zong is at number three in results with peak latencies are very high at night times. However, Zong 4G has good latency results in comparison to Warid 4G. Zong 4G has lower latency in all hours, although the trend is same here as well with latency increasing during 7pm to 12am.

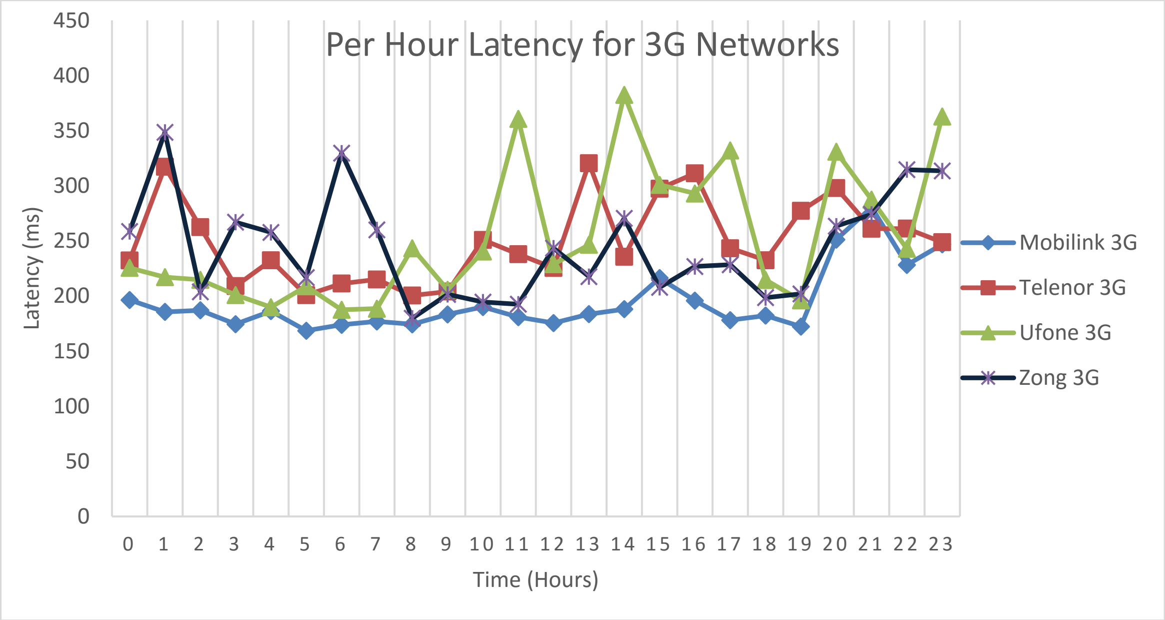

Figure 7 Line Graph for per hour latency to Facebook for 3G networks

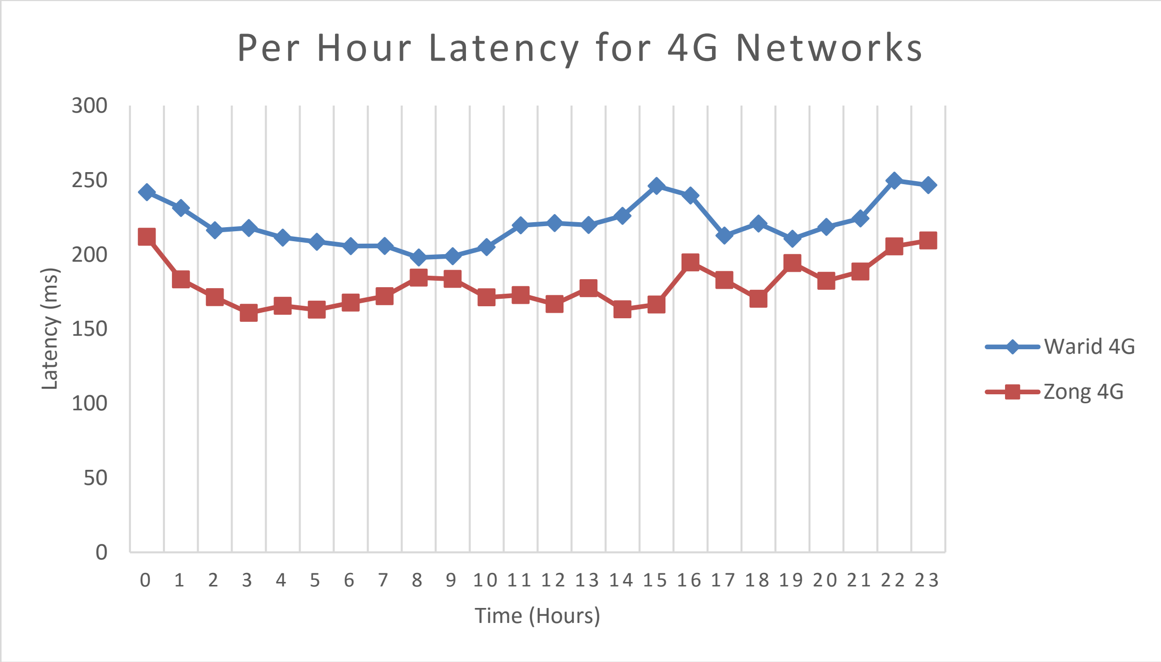

Figure 8 Line Graph for per hour latency to Facebook for 4G networks

4.1.3. 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 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.

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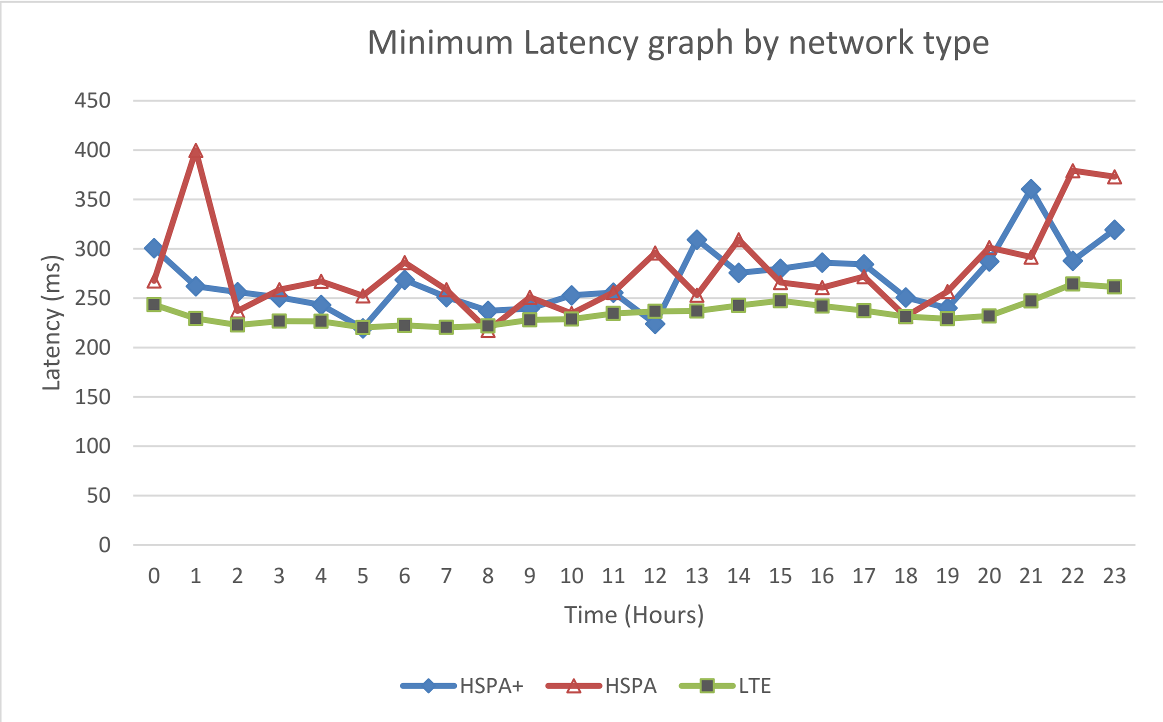


Figure 9 Line Graph for Minimum Latency by Network Type

4.1.4. Last Mile Latency

The last mile is the biggest reason of bottleneck for the end user. We calculated last mile latencies of all networks. 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 improved results in comparison to Zong 4g.

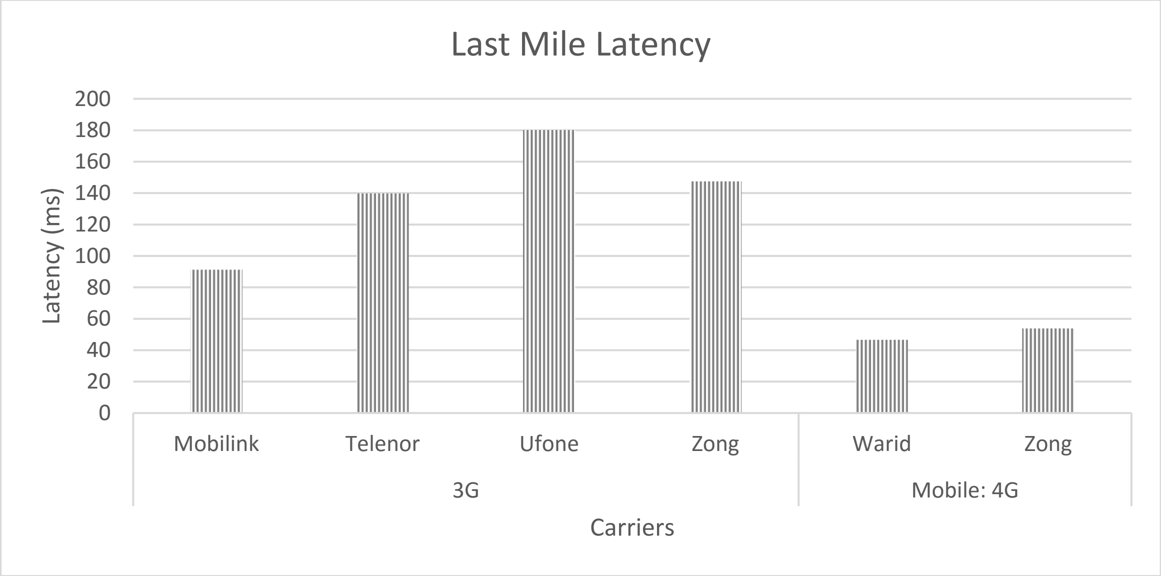


Figure 10 Bar Chart for Last Mile Latency

4.1.5. Ping Latency during Cable Damage Period

Figure 11 represents average latencies for duration of more than one month. Scale on y-axis is a logarithmic scale so small rise in bar reflects a significant increase in the data value. 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 in this period. As discussed earlier that there was fault in two main submarine cables that connect Pakistan to outer world SEA-ME-WE-4 and IMEWE, so latencies increased in this duration. However, after recovery of IMEWE cable latency values improved again as depicted in the figure. Reason behind this stability is that PTCL purchased additional bandwidth [33] that is being facilitated through IMEWE cable which helped in normalizing internet latency up to level that was in pre-cable damage period.

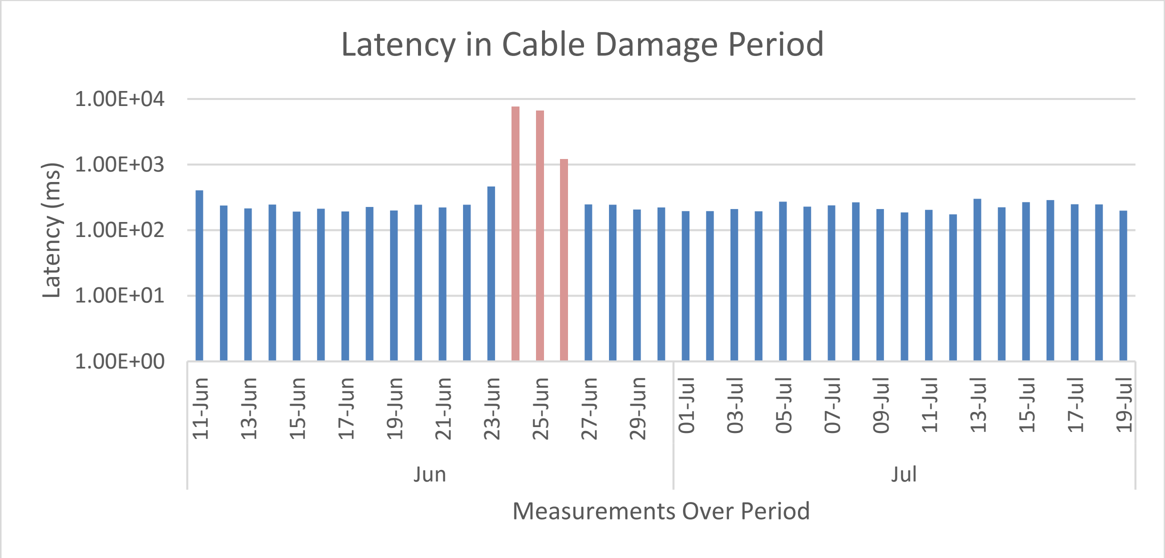
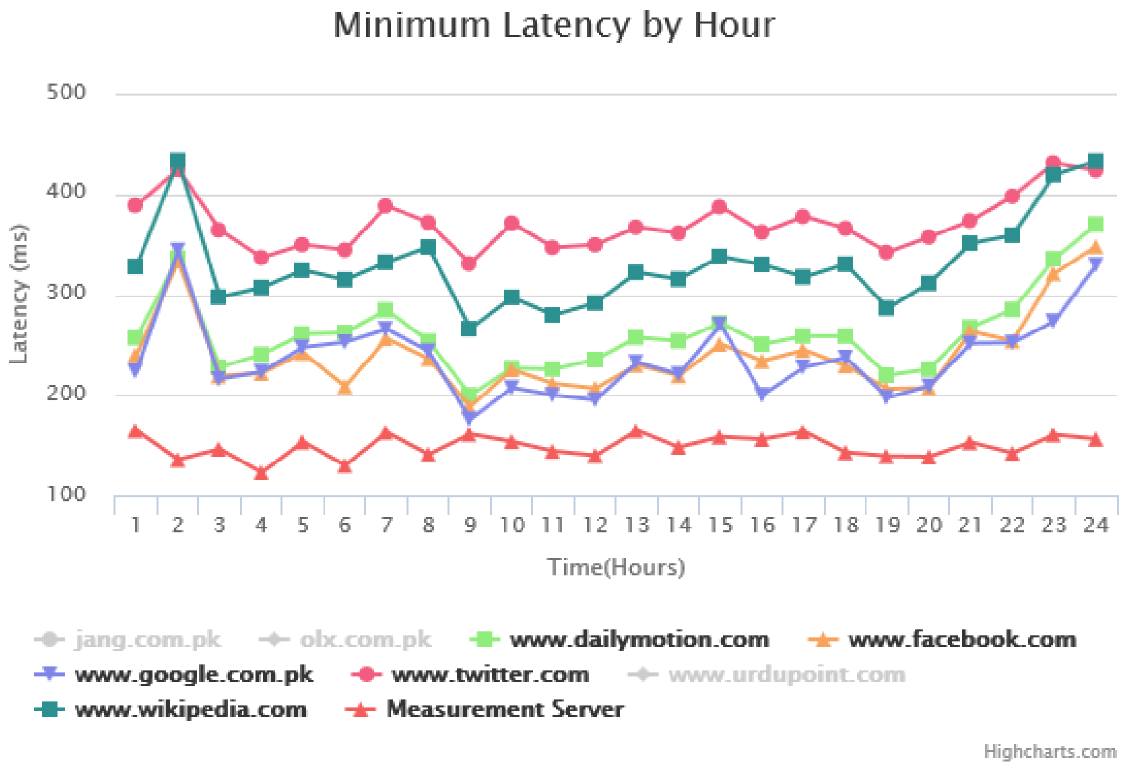


Figure 11 Box Plot of Ping Latency in Cable Damage Duration

4.1.6. Latency by Hour

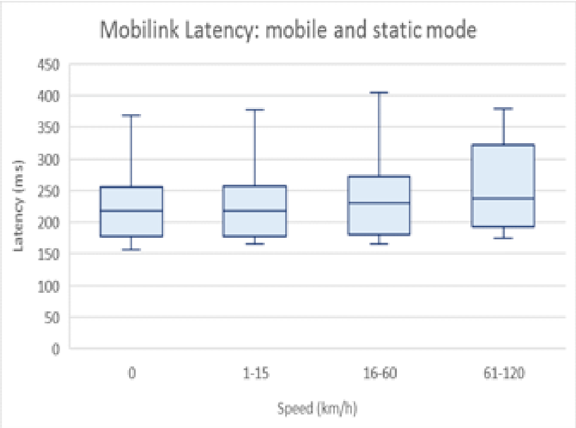
In this graph, we showed minimum latency against mostly accessed websites in Pakistan. We also showed latency against our measurement server which is locally deployed in Pakistan. Facebook, daily motion and google have lowest latencies from all international servers. Latencies increase at night times which are peak usage hours. Measurement server has least latency value in all hours contrast to other international servers. This graph highlights the benefit of local server infrastructure. Local server deployment will not only reduce latency, but it will reduce costs as well that incurs due to international traffic approaching from servers.



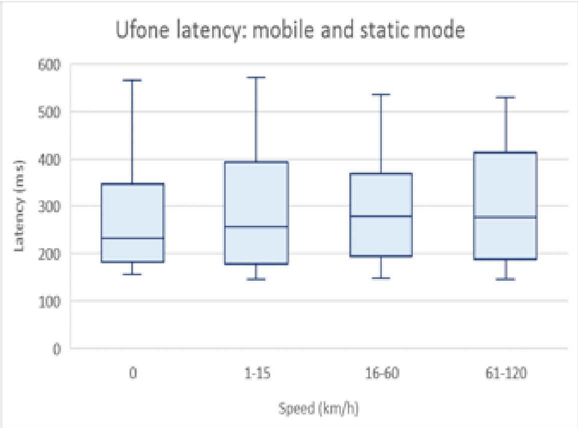
4.1.7. Latency in Mobile and static mode

This box plot shows median latency results from different websites based on mobile and static mode. Mobile mode is movement of person with speed greater than zero. We set three categories in mobile modes. Category one has range of greater than 0-15 Km/h. Category two has range of greater than 15-60 Km/h and range of category three is speed greater than 60-120 Km/h. By speed we mean, person's movement speed which is stored in km/h here. We anticipated speed by using Location class of android API. This API returns speed only when GPS is on.

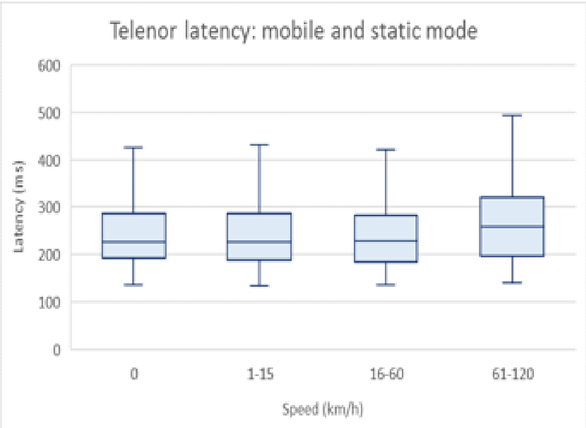
The graph shows the latency distribution of each career in mobile and static modes. For speed greater than 60 km/h however, latency values increased for each carrier which is as per standard says that results may get effected with increasing speed. Between 50-60 km/h, median latency increases for Mobilink and Ufone. On the other hand Telenor and Zong median latency results are almost same. From greater than zero to 15 km/h, median latencies are almost same for all networks except Ufone. It is observed that Ufone median latency increases between greater than 0-15 km/h. However, overall there is not a big shift in results under different speeds so we can say that speed up to 120 km/h has a slight effect on overall latency results.



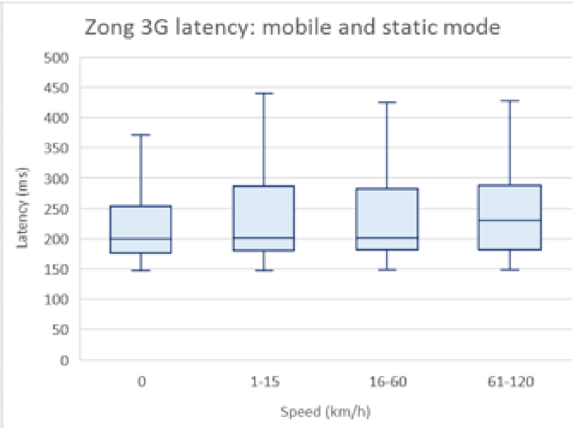
a) Box Plot of latency for Mobilink



b) Box Plot of Latency for Ufone

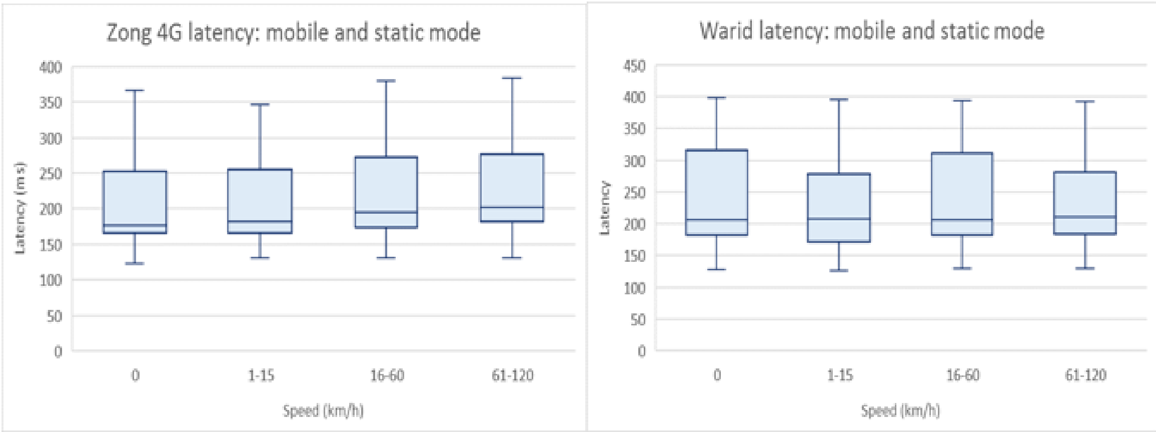


c) Box Plot of latency for Telenor



d) Box Plot of latency for Zong 3G

Figure 12 Latency for 3G networks in Mobile and Static mode



a) Box Plot of latency for Zong 4G

b) Box Plot of latency for Zong 4G

Figure 13 Latency for 4G networks in Mobile and Static mode

4.1.8. Latency with Signal Strength

Figure 15 shows latency dependency on signal strength. Figure shows latency relationship between latency and signal strength. Signal strength is displayed in dBm. Higher latencies are observed with weaker signals. However with improvement in signal strength especially from -91 and onwards, there is not much difference in results which suggest that signals weaker than -91 can cause significant disruption in achieving good QoS.

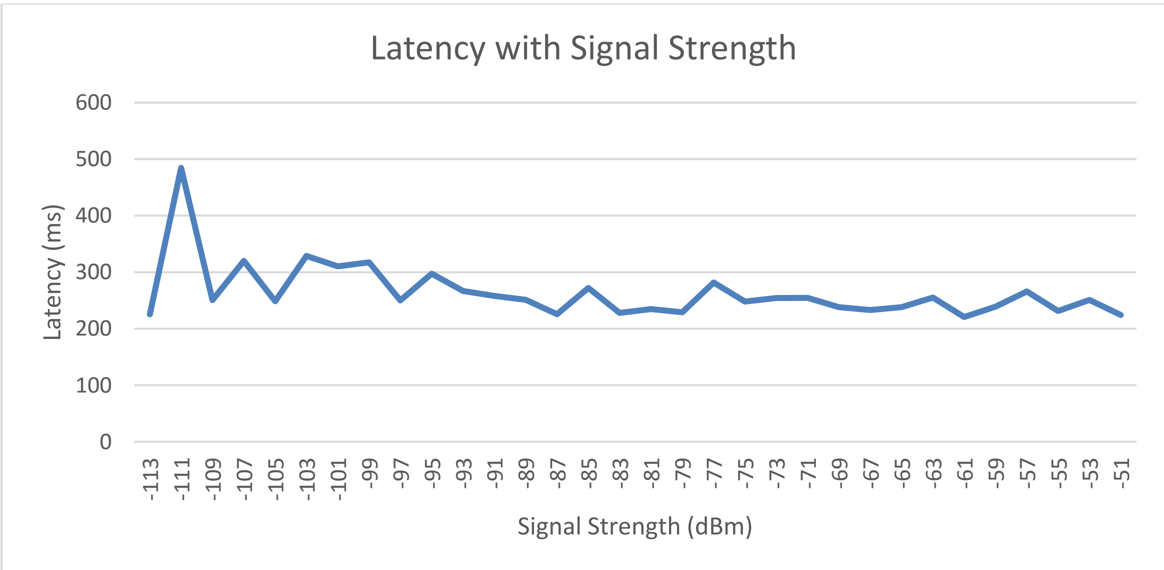


Figure 14 Latency with Signal Strength

4.2. Throughput

4.2.1. Downlink Throughput to Server

Among 3G networks, Mobilink is providing best service with mean of more than 7.5 Mbits/s which is by far best till now. Telenor downlink throughput is poor in comparison with others. Median of Ufone is also below 2.5 Mbits/s.

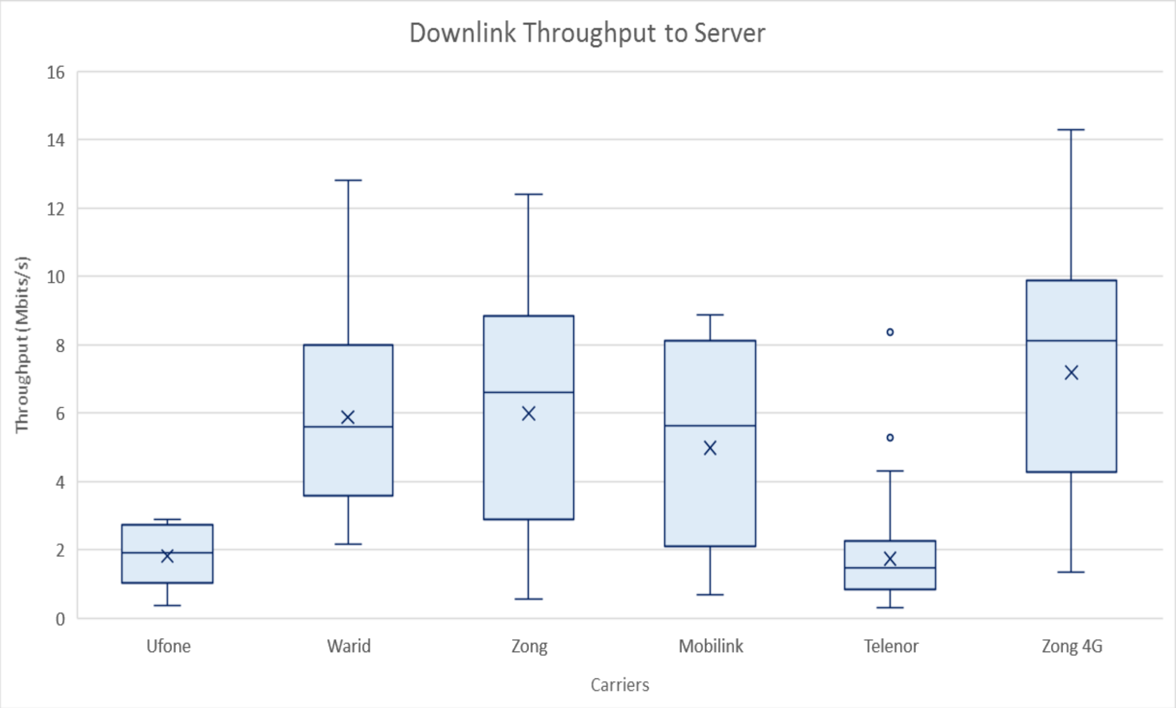


Figure 15 Box Plot of Downlink Throughput to Server

4.2.2. Throughput Variance in Chunks

Each throughput measurement calculated per second data rate for fifteen seconds. We calculated median of complete fifteen seconds duration measurement to calculate sustained throughput. Beside this, we are also interested to study the effect of shortening measurement 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. Results show that mean throughput of chunks is increasing from chunk 1 to chunk 3. So shortening the measurement duration from 15 seconds can result in less accurate data.

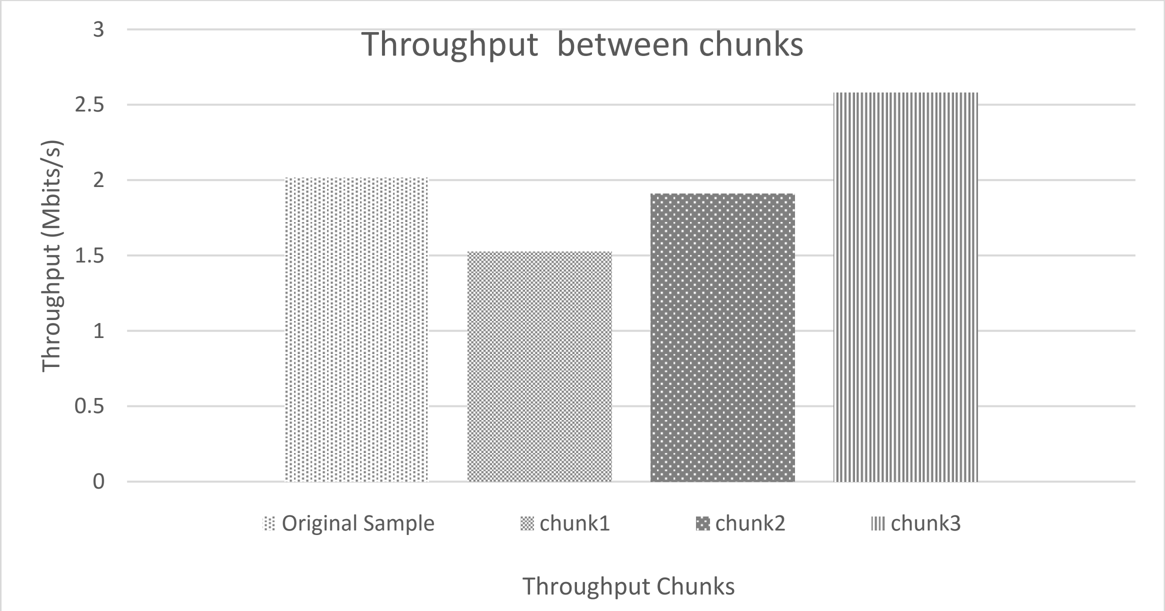


Figure 16 Bar Chart for Throughput Variance in Chunks

4.3. Jitter

4.3.1. Jitter per Network Type

Jitter in networks is quite high, 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 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 from the 3G carriers list.

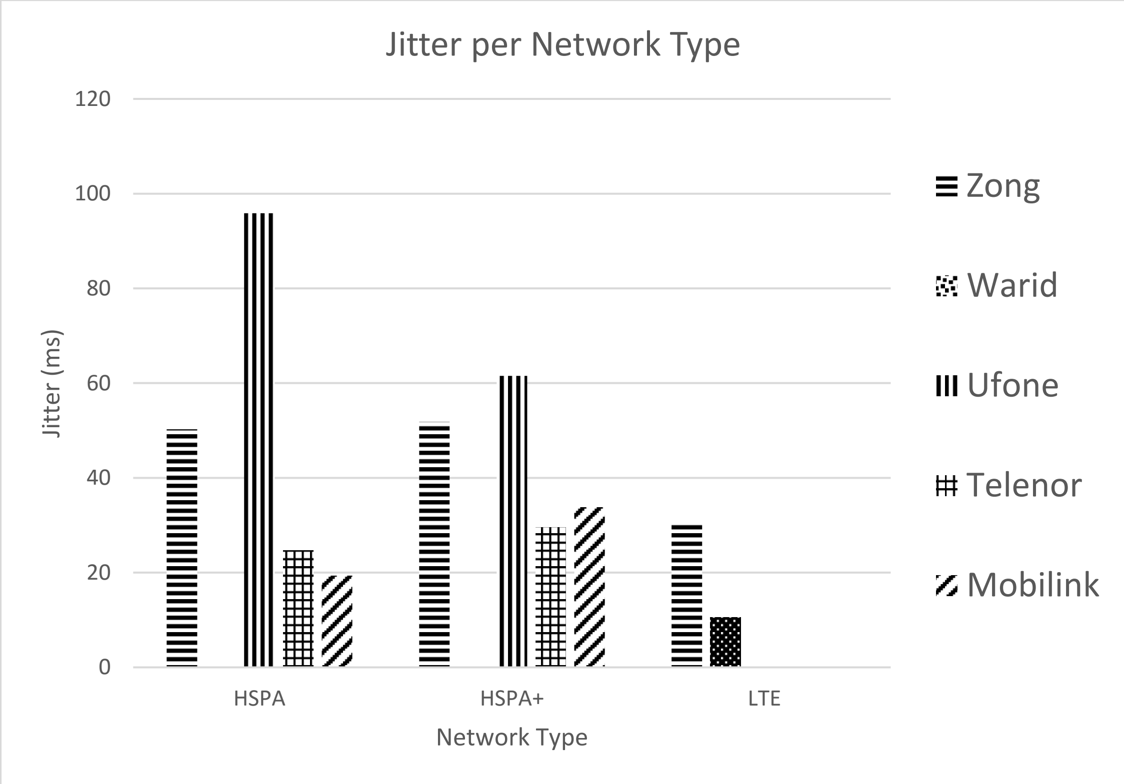


Figure 17 Bar Chart for Jitter per Network Carrier

4.4. Coverage

4.4.1. Average Signal Strength per Carrier

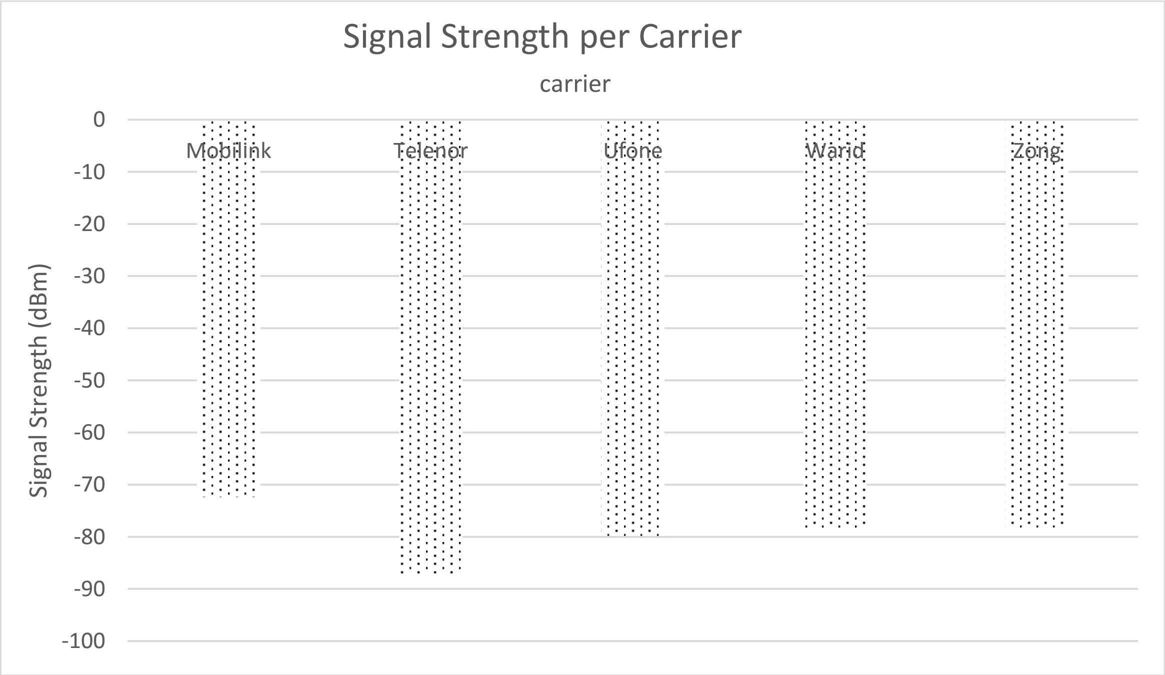


Figure 18 Bar Chart for Average Signal Strength per Carrier

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. Despite most of the measurements are from five main cities in Pakistan, signal coverage is not very good. Often the signal drops. According to the observations, Telenor has least average signal strength of -87 dBm. Mobilink is best with signal strength value which is more than -72 dBm.

4.5. Loss

4.5.1. Loss per Carrier

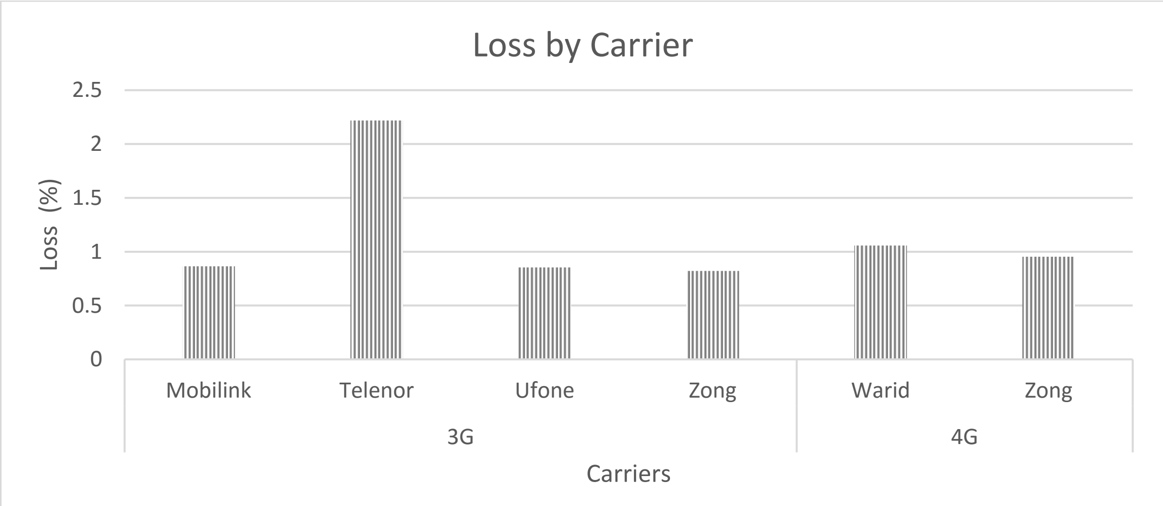


Figure 19 Bar Chart for Loss per Carrier

Losses cause a significant effect on network quality. Retransmissions adds latency and in case of real time traffic, users experience glitches. We calculated loss percentage of different network carriers. All networks have loss values under 2 percent except Telenor which has more than 6 percent loss ratio.

4.5.2. Loss per Network Type

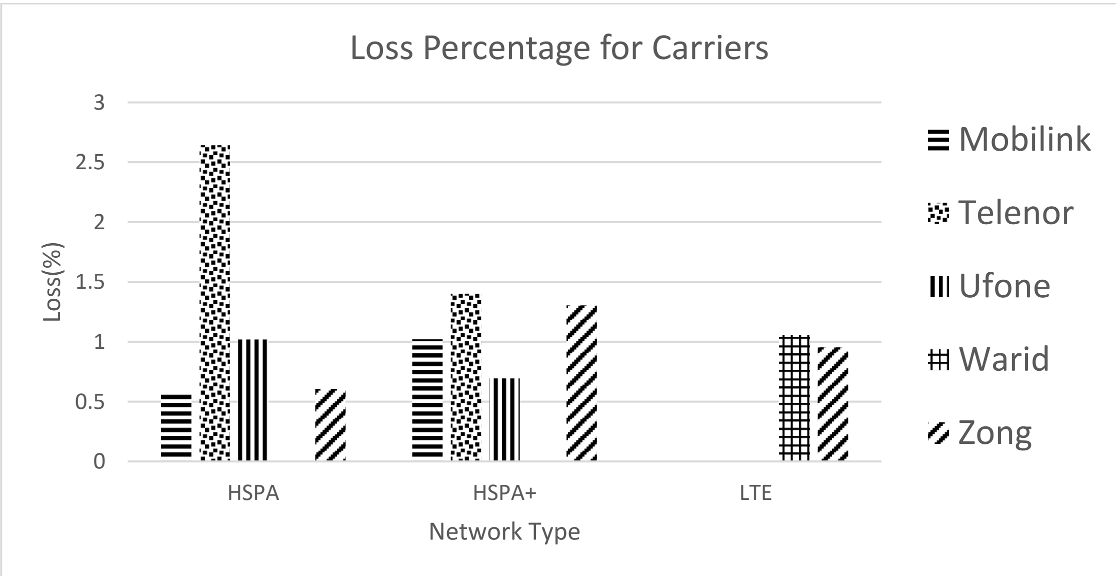


Figure 20 Bar Chart for Loss per Network Type

In our experiment, we also calculated loss per network type. In accordance to previous graph, Telenor is contributing most in loss for both 3G network types. However there is no specific pattern of loss among HSPA and HSPA+. Ufone and Telenor have a higher percentage of loss for HSPA as compared to HSPA+. Mobilink and Zong are exactly opposite. So network sub type (HSPA and HSPA+) doesn't have much effect as a whole on loss results. Among the carriers, Telenor is showing the worst performance in comparison to other networks. In LTE networks, loss percentage of Zong is just under 1 % which is slightly improved from 1.06 % result of Warid.

Chapter 5
Conclusion and Future Work

Our objective was to characterize the service quality of cellular broadband in Pakistan. To the best of our knowledge this is the first independent study on 3G and 4G networks. We expect that such an analysis can help in improving service quality levels of cellular broadband especially in a country like Pakistan where mobile broadband infrastructure deployment is at initial stages.

5.1. Contributing Factors to latency

Following are some contributing factors that cause performance degradation. Latencies are very high on average. One reason is that servers are geographically wide. Jang, Urdu Point also uses servers in USA. Another reason for performance degradation is poor signal propagation. Our main focus was big cities with expectation for well-established infrastructure so major cities that we included are Islamabad, Karachi, Lahore and Peshawar. However signal deteriorates at various places in these cities. We were also interested to see the performance of cellular devices during movement with speed more than 0 km/h. We studied the marginal effect on results with speed over 60 km/h. Under 60 km/h results are almost same just like these were in stationary cases. Some unusual delays are noted in the data set. Some latency results contain more than 40 seconds. One possible reason is buffer bloat. It may need more investigation into future work. If reason is buffer bloat then companies need to take appropriate measures to cater problem. They can reduce buffer size or use scheduler for optimized performance. Last mile latency is not only but important factor that causes performance degradation [16]. In our findings, Mobilink has an average latency under 100ms whereas other 3G networks have an average latency well over 100ms and Ufone touches almost 200ms. In comparison, last mile latency founded in a study in South Africa was under 100ms[16]. By reducing last mile latency and bringing it under 100ms or more would cause significant improvement in mobile network performance.

5.2. Problems

During the experiment we faced several issues. There were lots of security and trust issues among people to participate in the study. To overcome this. We make sure users' privacy and hashed all personally identifiable information. We also introduced slight inaccuracy in location based information so that exact location could not be tracked. Specific decimal value is added that changes location slightly, however it does not effect on speed calculation as this inaccuracy is added after acquiring all results and just before sending the result to the server.

Measurement server acquisition was another issue with enough bandwidth to fulfill our requirements. We are thankful to the National Center of Physical Islamabad for their generous offer to use their server.

5.3. Conclusion and Future Work

There is a lack of local infrastructure. None of mostly used servers 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.

3G/4G structure is in initial stages covering only big cities. Signals deteriorate and often strength stays low. 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.

Performance of Mobilink network is best in 3G networks followed by Zong. 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 has upper hand than Zong 3G. Median latency to international servers and loss percentage are only two parameters where Ufone competes with Mobilink and Zong.

Like Ufone, Telenor does not dominates in any test scenario however in jitter it competes 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.

We are interested to study the effect of radio resource control (RRC) on measurement results. These are different states that represent channel acquisition status. How transitioning between different states effects on data in both HSPA and LTE networks will be main focus. We are also looking forward towards censorship studies in cellular broadband. Studying censorship techniques used in mobile networks and its comparison with techniques that are used in wired network will be the part of our study.

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Annex

Annex presents a detailed set of contextual parameters for each mode. These contextual measurements are useful in data analysis along with actual network measurements.

Mode	Measurement Parameters
Battery	Technology, plugged, scale, health, voltage, level, temperature.
Device	PhoneType, phoneNumber, softwareVersion, phoneModel, androidVersion, phoneBrand, deviceDesign, manufacturer, productName, radioVersion, boardName, networkCountry, networkName.
GPS	Latitude, longitude, altitude, speed.
Network	Network Operator Id, network Type, connection Type, wifi State, cellType, cellId, cellLac, networkId, systemId, dataState, dataActivity, signalStrength
Sim	SIM Network Country, SIM State, SIM Operator Name, SIM Operator Code, simSerialNumber