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Revisiting the State of Cellular Data Connectivity in Telangana

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ABSTRACT

The count of mobile Internet users in India has been growing at a rate of 27% annually and is expected to reach300MB by 2017. There is however limited understanding of whether this rapid growth is happening while also ensuring that good quality of service is provided to users. To and out, building upon our earlier work [17] we deployed a measurement framework in 20 rural, semi-urban, and urban sites in North India and probed four leading 2G and 3G telecom providers to measure performance metrics such as availability, throughput and latency. We also observed some design and conjuration aspects of cellular networks that affect the quality of service perceived by users. Our results point to many instances where miss conjurations or inadequate provisioning or poor monitoring of cellular networks led to signicantly low performance provided to users. We are now Using these results to argue for more robust Quos regulation in the country, and show how the current regulations for 2Gand 3G services are not sufficient to hold providers account Able for the quality of service provided by them.
Keywords : Cellular data networks, Measurement, Performance, Reliability, Reliability, availability, and serviceability

I. INTRODUCTION

The rapid proliferation of mobile phones seen around the world, and optimistic projections for the growth of mobile Internet in developing regions in the next few years, have indeed become legendary tales in the information technology revolution of the 21st century. In fact, persuading voice users to convert to using data services has spawned an inof relevant content and services, which if not enabled well can become impediments to the adoption of data services. In this paper, we focus on the rest challenge, that of in-restructure quality, and investigate the quality of service currently provided on 2G and 3G networks in India. While acquiring new users, telecom providers need to expand their infrastructure in tandem to cater to the increased Demand. However, consumer complaints are noted commonly in India that providers are not able to meet the quality of service committed by them [7]. The regulatory environment in India is quite proactive, and TRAI (Telecom Regulatory Authority of India) has taken several measures to hold providers accountable for meeting minimum A recent report by the Telecom Regulatory Authority of India notes that India has about 860 million cellular network subscriptions [8]. With wired broadband (> 256Kbps) connectivity available to less than % of the population [8], cellular data connectivity provides an avenue to bridge the digital divide and provide Internet access to the rural regions of India. There s, however, little understanding of performance of cellular data connectivity in India. While there have been studies regarding cellular data networks in the developed world [4, 19, 20], with recent attention to understanding data usage and TCP performance on 3G/4G networks [18, 31], such studies have not been performed in India. Inthe absence of systematic studies and with cellular service providers always advertising maximum achievable physical data rate, one is left to rely on anecdotal. We do this by collecting performance data on throughput, latency, and availability from 20 sites in rural, semi-urban, and urban areas in North India, and give concrete evidence that the QoS provided differs considerably reported by the providers to TRAI, and show that the values differ substantially and that more realistic test environments should be mandated by TRAI to mimic the actual user experience with cellular data services. We also show through two examples that better infrastructure monitoring and more careful network conjurations can help improve the QoS even with the current infrastructure { providers who have con_gured smaller buffer sizes in their network elements are able to provide better latency, and similarly providers who have con_gured less reactive switching between 2G and 3G are able to avoid certain detrimental interactions with the higher layer TCP protocol that impacts the through- put achieved. Overall, we highlight the need for telecom providers to manage their networks more efficiently and provide better QoS to consumers, who currently do not seem to be getting the service to which they are entitled. As part of a larger effort in this project, we have partnered with a consumer rights organization to now take these to TRAI and other regulatory bodies, and push for urgent revisions on QoS regulation in the country. Much of the works cited above conducted measurements in the developed parts of the world. Developing regions are likely to exhibit interesting characteristics though, and several researchers have worked in this context. [15] Prowled Internet usage in a small community in Zambia which got its backhaul connectivity through a low bandwidth satellite link, but with fast wireless meshes within he community. It revealed the need for efficient aching and peer to peer solutions to keep the traffic coal. [29] conducted measure- mints in Ghana and found that due to a lack of server infrastructure locally, draw attention to the degree of connectivity etweenISPs and peering with CDNs, along with keeping a focus also on the quality of network conjurations and monitoring by different telecom in I Telangana.

II. METHODS AND MATERIAL

CELLULAR DATA TECHNOLOGIES

The evolution of cellular data technologies over the past 15years has been complex. Multiple generations of technologies have been introduced, with multiple standards spanning each generation, and each standard defining a variety of modulations, data rates, and device classes. The situations further complicated by differences in the technologies de- played around the world and differences between standards' names and marketing terms used to popularize them. This section provides a brief history of cellular data technology evolution and identifies technologies deployed in Telangana. The Third Generation Partnership Program (3GPP) and Third Generation Partnership Program 2 (3GPP2) were created by telecom standards development organizations to guide cellular data standards development based on GSM and CDMA technologies, respectively. Table 2 shows the standards introduced under the 3GPP and 3GPP2 umbrella [5].While GSM networks evolved to GPRS and EDGE, which further evolved to HSPA networks, the CDMA networks evolved to 1xRTT followed by 1xEV-DO. Typically, data technologies prior to 3G are commonly referred to as 2Gtechnologies although there are significant differences in data rates between technologies within the same generation. In India, a majority of the operators use GSM technology and hence have evolved to EDGE, HSDPA, and HSUPA.Only three out of a total of 13 service providers across India [25] operate on CDMA and have evolved to 1xRTT and1xEV-DO. In this paper, we consider one CDMA-based ser-vice provider and three GSM-based service providers.

Table 1: Key Results of Cellular Data Measurements

Property	Key Result	Section
Availability	None of the rural regions instrumented by us has access to 3G connectivity. Dindori, a semi-urban location has access to 3G connectivity intermittently.	5.1
Throughput	A large percentage of TCP flows experience long periods of inactivity stalling the flow and also resulting in timeouts. We call the phenomenon a *connection stall*, which seems to be related to either burstiness of the flows or number of in-flight packets.	5.2
Latency	Ping RTTs measured across all the service providers are significantly higher than those observed in the developed regions. Analysis shows that EDGE/HSDPA air interfaces are not the cause of high latencies; rather, it is likely that network configuration causes them.	5.3
Content Placement	Placing content within the service provider network can reduce round trip latencies. We find that some websites have placed content within three of the four service provider networks we evaluate. We also find that latency to the in-network servers are generally lower by 50%.	5.4
Urban Provisioning	One service provider, Airtel, provisions preferentially for urban regions. This is noticed in higher throughputs and lower latencies in Delhi, our urban measurement point, using the same access technologies as the rural regions.	5.4

Table 2: Evolution of Cellular Data Technologies.

Group	Family	2.5G	2.75G	3G
3GPP	GSM	GPRS, HSCSD	EDGE	WCDMA, HSDPA, HSUPA, HSPA+
3GPP2	CDMA	1xRTT		1xEV-DO (Release 0, Rev A, Rev B)

RELATEDWORK

In terms of methodology, our work comes closest to [18] and research on large scale measurement of broadband networks [23, 19, 2, 8, 10], all of which have highlighted the need to understand network conditions from the end user's point of view. Users are impacted by Policies and capacity provisioning of edge ISPs with aspects like buffer sizes and traffic shaping having a significant impact on the QoS experienced by the users. Our measurement architecture is similar to Neutralizer, and we have also borrowed several techniques from these papers to probe _re-walls, caching, etc reported in our earlier research [17]. Similar work of large-scale probing of the network edge is however not common in the cellular data connectivity space. Cellular network measurement research has actively covered TCP behavior on cellular networks [14, 12, 4, 5], and has also seen interest in understanding hardware characteristics such as the radio wake up latency and scheduling policies [3, 9, 21,25] with the broad objective to tweak protocols so as to obtain better performance on cellular data networks. Our own focus in this paper is not on network protocol medications to get better performance, but to conduct measurements on2G and 3G networks in the developing region context of India to understand the current state of QoS experienced by the users. Our goal is to specially use the measurements to reason about appropriate regulatory mechanisms that can help ensure that telecom providers will work towards better quality of service provisioning for the users. Much of the work cited above conducted measurements in the developed parts of the world. Developing regions are likely to exhibit interesting characteristics though, and several researchers have worked in this context. [15] ProledInternet usage in a small community in Zambia which got its backhaul connectivity through a low bandwidth satellite link, but with fast wireless meshes within the community. It revealed the need for efficient caching and peer to peer solutions to keep the traffic

of these networks, particularly, the performance of TCP on them received much attention [4, 19, 20, 29]. While the field measurements reported near theoretical through-put values [27, 32], the packet-level evaluations provided several insightful observations [12]. For example, Chakravorty et al. [6, 7] showed that small initial congestion window combined with large RTT (> 1000ms) caused ineffective use of available bandwidth as it took a long time to fill the network pipe during slow start and hence impacted small file transfers. They also showed that large buffer size sat gateways, a phenomenon nowadays referred to as "buffer bloat" [16], cause large delays in interactive applications antic SYN timeouts during new TCP flow creation. They Recommended use of a transparent proxy between a GPRS client and a server, where the proxy uses a large initial window to send data to the client while advertising a smaller receive window to the server to reduce impact of queuing. Subsequently, several recommendations for improving TCPperformance on cellular networks have been evaluated [15,1].More recently, several studies have evaluated the performance of 3G networks in the developed world [28, 26, 24,31]. While these measurements are predominantly on access technologies different from those deployed in India, we summarize results relevant to our work. Elmokashfi et al. [10] evaluated latencies on two HSPA and one EV-DO networks in Norway and reported that the delay characteristics depend mainly on network configuration rather than location or measurement device. They also note clear diurnal pat-terns in latencies. In contrast, measurements by [31] in Hong Kong show significant customization in cell-by-cell manner according to demographics of individualists. Jurvansuu et al. [18] evaluate performance of TCP on WCDMA and HSDPA networks and find that HSDPA pro vides an improvement in TCP throughput over WCDMA, but the improvement is modest, particularly for short duration flows. Conjunction with recent studies on Internet usage in developing regions [14, 3], our work helps in broadening our understanding of the experience of using the Internet in developing regions. Our goal is to obtain an understanding of basic network properties such as throughput, latency, DNS lookup times of cellular service providers in rural India. At a architecture consisting of appropriate hard-ware and software that can be deployed in rural challenges and concludes with a description of our measurement campaign.

METHODOLOGY

Our goal is to obtain an understanding of basic network properties such as throughput, latency, DNS lookup times of cellular service providers in rural India. At a high level, we are presented with two challenges. The first challenges selection of locations in rural India for conducting measurement campaigns. The second challenge is to design measurement architecture consisting of appropriate hard-ware and software that can be deployed in rural locations, require minimal manual intervention, and efficiently cope with the challenges on the ground such as electricity out-ages, rodents in the building chewing cables, and minimal technical support. This section describes how we addressed these challenges and concludes with a description of our measurement campaign.

Measurement Sites and Service providers

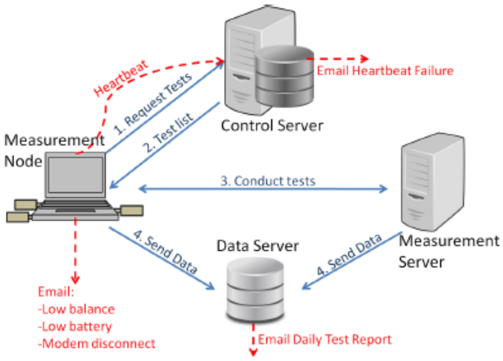
During the conceptualization of our work, we determined that the logistics of us manning remote measurement locations is daunting because accessing rural communities is of-ten very difficult and also because working relationship with locals of these communities is necessary for a successful ex-pediment campaign. Although the logistics of location identification and equipment setup and maintenance are mundane activities from research perspective, they nevertheless are quite challenging and, like in our case, often dictate with PRADAN, a NGO that has presence in over 4,000 villages across eight of the poorest states in In-dia. PRADAN provided logistic support for our experiment campaign. They helped in selecting locations and service providers for measurements, finding appropriate transport to reach the locations, and finding food and accommodation. We chose BSNL, Airtel, Idea, and Reliance as four different service providers for measurements. BSNL, Airtel,and Idea provide data connectivity over GSM based technologies EDGE and HSDPA, which we refer to as G1, G2,and G3 respectively for the rest of the paper. Reliance pro-vides connectivity over CDMA based technologies 1xRTTand 1xEV-DO, and so we refer to it at C1. At any given location, three best service providers were evaluated, the choice of which was based on knowledge of local PRADAN staff about providers' connection quality and pilot measurements conducted at the location. Overall G1 and G2 were evaluated in 6, G3 in 5, and C1 in 3 locations. Table 3 shows the access technologies available at our measurement locations. We note that in S1, the access technology fluctuated between EDGE and HSDPA, resulting in some measure As reported in an earlier paper [17], during 2013 we collected 2G and 3G measurements from 7 rural and urban locations, having probed each location for a period of at least 3 months. We have since then repeated the measurement exercise in more locations, bringing the count of the total number of rural and semi-urban sites probed to 15,and urban sites to 5. The methodology followed was the same as in our earlier work. We wrote a measurement suite on Linux based Net books which were placed at these sites, and were conjured to run tests to measure the through put ,latency, availability, etc of 2G and 3G connections provided by different place our equipment for a long stretch of time over several

Table 1: Measurement locations/service providers

	G_1 (BSNL)	G_2 (Airtel)	G_3 (Idea)	C_1 (Reliance)
R_1 (Lamta, MP)	EDGE	EDGE	-	1xRTT
R_2 (Paraswada, MP)	EDGE	EDGE	EDGE	-
R_3 (Ukwa, MP)	EDGE	EDGE	EDGE	-
R_4 (Amarpur, MP)	EDGE	EDGE	EDGE	-
R_5 (Samnapur, MP)	EDGE	-	-	1xRTT
R_6 (Janakpur, MP)	EDGE	-	-	-
R_7 (Manjha, MP)	-	EDGE	-	1xRTT
R_8 (Hanumanpura, RJ)	EDGE	EDGE	EDGE	-
R_9 (Kulhi, JH)	EDGE	UMTS	-	-
R_{10} (Gondlipokhar, JH)	EDGE	UMTS	-	-
R_{11} (Getalsud, JH)	UMTS	EDGE	-	1xRTT
S_1 (Dindori, MP)	EDGE	-	-	-
S_2 (Panna, MP)	EDGE	UMTS	UMTS	-
S_3 (Jatadungari, MP)	-	-	EDGE	-
S_4 (Ormanjhi, JH)	-	EDGE	UMTS	-
U_1 (Pondi, MP)	EDGE	-	-	1xRTT
U_2 (Jaipur, RJ)	UMTS	UMTS	EDGE	-
U_3 (Sikar, RJ)	UMTS	UMTS	EDGE	-
U_4 (Ranchi, JH)	EDGE	UMTS	-	-
U_5 (Delhi)	UMTS EDGE	UMTS EDGE	UMTS EDGE	EVDO

Measurement Architecture

Ployments, thus focusing on robustness, flexibility to change the suite post deployment, and remote monitoring. Figure 1shows the key components of the architecture. Our measurement clients are low cost net books with 1GHzprocessors, 1GB RAM, and three USB modem ports. Thenetbooks provided about 10 hours of battery backup, which allowed us to conduct measurements through several hours of power outages - a frequent phenomenon in rural India. Additionally, we were able to connect three USB modems teach computer reducing the cost of deployment per modem. The modems used were Hawaii E173 for EDGE/HSPA net-works and Hawaii EC159 for 1xRTT/1xEV-DO networks. Both the modems were capable of handling throughputs ad-vertices by the service providers. The measurement client is preconfigured with a unique node ID and information about the service providers and corresponding access technologies to be used. For each topple of (client id, service provider, access technology), the client requests the control server for a list of tests to be con-ducted. The control server looks up a database to respond tithe request. The control server also provides all the relevant parameters for executing he tests. For example, when con-ducting a latency test using ping, the control server provides the IP address of the measurement server and the number of ping packets to be sent. Using the information from the Control server, the client conducts a list of tests, the results of which are then uploaded to the data server. The measurement server also collects data like packet level traces and uploads them to the data server. Our measurement architecture design draws upon prior work by Kreibich etal. [21], borrowing the key concept of having a separate con-troll server to serve the tests to be conducted by the client. Flexibility: A separate control server that decides what tests to run provides significant flexibility, which we outline from our own experience here. We use the control server to specify different file sizes to download depending on the access technology. In addition to the measurement tests we have also included additional commands like download, upload, and install on the client that can be executed when requested by the control server. We use these commands toad new tests to our client and also upload the test results to the data server. Finally, there have been situations where command-line access to the clients was required, for which we created a new command that creates an SSH tunnel and then sends an email notification to us. We are now able to Connect to any of the clients by making the client execute this command via the control server.



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Measurement Tests

Since there is little information available about cellular data connectivity in India, we focused on understanding the basic network characteristics like throughput, latency, IP address allocation, and existence of middle boxes. Table 4summarizes the tests reported in this paper. For each (client, service provider) tulle, the periodic tests included throughput, latency, and DNS lookup time tests. We used pier to run a single TCP flow in downlink direction to measure downlink throughput. A similar at each client, tests for eservice provider repeated 4.5 hours. We logged the IP addresses assigned to the clients and the DNS servers provided when a new connection is established. We also conducted additional tests such as testing the existence of NATs, HTTP proxies, and web caches in the service provider networks using Metalize [21]. These tests were conducted only once as they capture properties of ser-vice provider networks that rarely change. Finally, metrics like signal strength reported by the modem and the access technology being used by the modem to talk to the base station were logged every 2 seconds.

III. RESULTS AND DISCUSSION

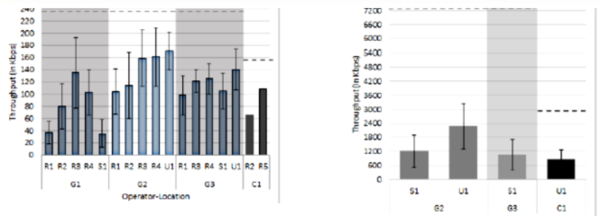
1. Throughput

Are the achieved throughputs close to their theoretical maximums? Figures 2 and 3 show the average 2G and

3G throughputs measured across locations and service providers3 along with the standard deviation in the throughput measurements. The horizontal dashed line shows the theoretical maximum throughput achievable by a client in ideal circumstances. The achieved throughputs are (as may be expected) significantly lower than their theoretical maximums. The 3Gconnection, however, appears to provide reasonably good "broadband" like performance (> 256 Kbps). Next, we consider the impact time-of-day and day-of-week has on the measurements. Are throughputs better at night or on weekends? We find diurnal patterns in G2 EDGE networks in both the uplink and downlink directions with _ 25% higher through

Table 4: Description of tests conducted at each client for each service provider.

Test Category	Description	Frequency
Throughput	iperf was used to run a single TCP downlink/uplink flow for 5 minutes.	Every 4.5 hours
Latency	A set of 30 ICMP ping packets were sent to 20 landmark nodes. Average RTT of the 30 packets formed one measurement point. Traceroute to landmark nodes was executed and the IPs of intermediate hops were looked up in a WHOIS database.	Every 4.5 hours
Local DNS lookup	Two consecutive DNS look ups for `www.google.com` were done at the DNS server specified by the service provider and latency for each look up noted.	Every 4.5 hours
New Connection Tests	We noted IP address assigned and DNS servers allocated when a connection was established	Every new Internet connection
One Time Tests	Netalyzr was used to note existence of NATs, HTTP proxies, and web caches.	One time



2. QOS Measurement Results

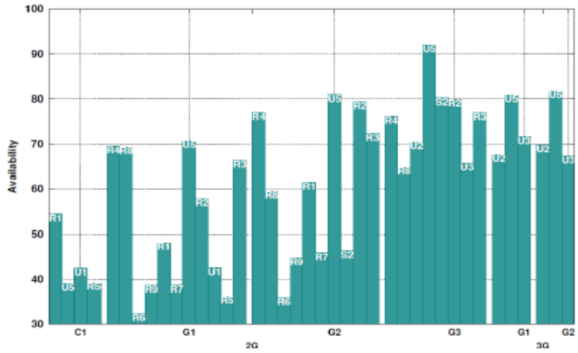
With the objective to understand the QoS provided by telecom providers, we probed three key metrics: availability, upload and download throughput, and latency, at all the measurement sites. We then compared this data with the values reported by telecom providers to TRAI.

Availability

For each service provider at each location, we evaluated the fraction of time for which connectivity was available. To do so we time stamped network connection and disconnection events reported by the USB modems during the time when the upload/download/latency experiments ran on the modems, and also noted any modem down times during this period when the modem was not responding and re-mounting attempts were being made by watchdog scripts. Using this we calculated the availability as:

$$availability = \frac{connected\_time}{(measurement\_duration - down\_time)}$$

in the cellular network. We also compared this to the end to end latency to the measurement server, to understand what proportion of the latency is spent in the radio access network.



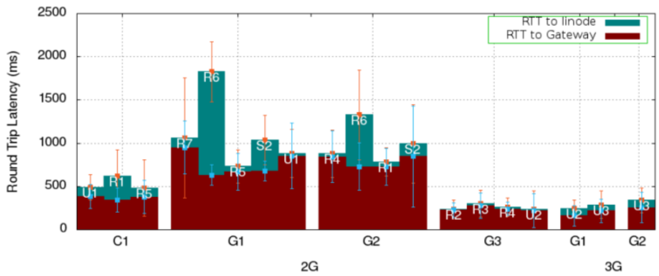


Figure 4 shows the round trip latencies to the measurement server, and its sub-component to the gateway node in the network. It is interesting to note that providers like $G3$are able to provide almost 3G like latencies on 2G such as nutrition labels [24] could also help empower consumers by making them more aware of the QoS to expect and then use the information to make better choices when buying data plans. However, unless TRAI does not mandate some minimum QoS standards to which providers can be held accountable, or the published information is not made available to consumers easily to be able to exercise their choice in selecting providers, even these stronger regulatory measures may arguably not yield much beets. We therefore believe that TRAI should continue to mount pres-sure on the providers to manage their networks better since our data indicates that just careful network con_gurationsalone can help to a sign cant extent.

3. Network Connectivity

We next explore inter-ISP connectivity and CDN linkages of cellular providers because these aspects innocence the quality of service perceived by users [29, 6].We start with listing some common CDN providers, and then use trace route and the RIPE database to chalk out AS hops to these CDN networks from the four cellular providers probed by us. Figure 6 shows the consolidated AS map. We can see from the map that Bharti Airtel and Tata Com-medications (which acquired a controlling stake in the state owned VSNL network in 2002 [11]) hold dominant positions in providing backbone connectivity for India with the rest of the world. We also interestingly _end that providers like $G3$ to provision additional infrastructure.Another observation from Figure 4 is that the latency be-yond the gateway is also lower for $G3$ and $C1$, indicating that these ISPs are likely to have better connectivity with.

Table 3: Comparison of performance metrics observed by us with TRAI reported values by service providers

Location		Observed Values			TRAI Values		
		Availability (%)	Throughput (kbps)	Latency (ms)	Availability (%)	Throughput (kbps)	Latency (ms)
RJ	2G	59.49	131.02	308.45	100	116.5	206.3
	3G	69.73 - 71.58	1394.03- 2187.13	128.84 - 256.89	100	2476.3	191.8
JH	2G	41.97 - 57.64		453.85 - 1040.75	100	199.7	244.8
	3G				100	3485.2	64
MP	2G	36.37 - 80.17	85.89 - 160.72	405.16 - 936.45	99.83	131.8	119
	3G	73.66	907.80	476.57			
Delhi	2G	81.44	167.82	310.58	100	130.2	173.3
	3G	91.69	2332.25	540.41		2369.4	80.4

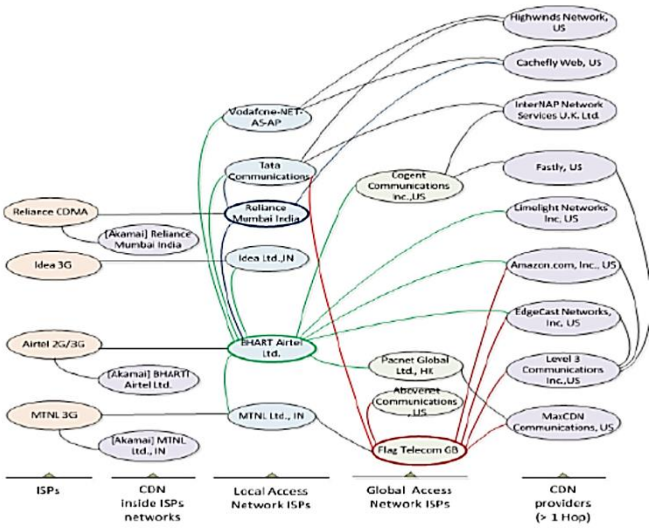
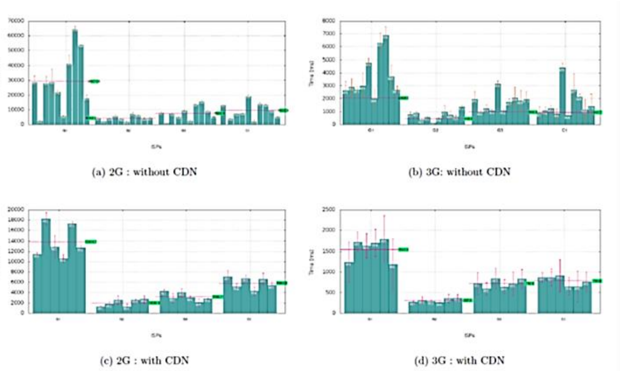


Table 4: Pageload time for websites without CDN

Website alias	Page alias
http://www.ibps.in/	W1
http://www.incredibleindia.org/en/	W2
http://india.gov.in/	W3
https://www.irctc.co.in/eticketing/loginHome.jsf/	W4
http://www.kerala.gov.in/	W5
https://www.maharashtra.gov.in/	W6
https://morth.eproc.in/ProductMORTH/publicDas/	W7
http://www.odisha.gov.in/portal/default.asp/	W8
https://www.sbi.co.in/	W9
http://www.tn.gov.in/	W10



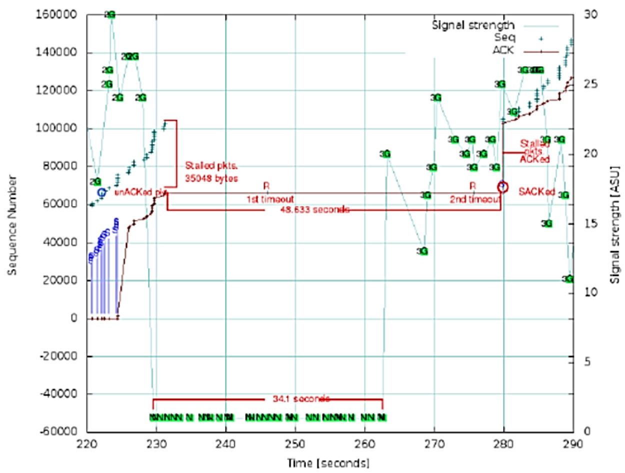
(a) 2G : without CDN

(b) 3G: without CDN

(c) 2G : with CDN

(d) 3G : with CDN

Website alias	Page alias	CDN provider
http://timesofindia.indiatimes.com/	W1	Akamai
http://www.espncricinfo.com/	W2	Akamai
http://www.bbc.com/bbc/	W3	Fastly
http://www.bostonmagazine.com/	W4	Internap
http://www.news.com.au/news/	W5	Akamai
http://www.yatra.com/yatra/	W6	Akamai



IV. CONCLUSION

We showed through our measurements that the quality of service obtained by users differs considerably from ad-verities' values by the telecom providers, and from values reported by them to the telecom regulatory authority in In-dia. We also showed that in many cases just more carefulcon gurations of the cellular networks could lead to better performance. We are now working together with a consumer rights organization to take up this evidence to the government regulators and argue for stronger QoS regulations in the country. We have conducted active measurements across 5 rural,1 semi-urban, and 1 urban location over four different cellular service providers using our measurements framework designed for operations in rural locations.

V. ACKNOWLEDGEMENTS

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