www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 4 Issue 4 April 2015, Page No. 11621-11627

Analysis of Characteristics of 2G/3G Cellular Networks in rural and urban areas of Delhi

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Abstract: ***Recent years India has experienced significant growth in cellular penetration and it is the second largest and fastest growing mobile market in the world according to recent report by the Telecom Regulatory Authority of India. In this paper illustration of cellular data networks available in India is done. Throughput latency, Availability and other network characteristics of five cellular service providers (Idea, BSNL, Reliance, MTNL and Airtel) across six locations are evaluated and a robust, scalable, and extensible suite to conduct active client side measurements in rural regions is designed. Variety of tests has been done over 90 days by measuring the following key insights about the cellular data and understanding of such network parameters and their impact on performance will help to explore the strategies for optimizations at end-hosts as well as within the service provider network.***

Keywords: latency, throughput, cellular network.

1. Introduction

Now days, there has been a significant growth in cellular communication mainly because of technological growth in cellular networks and drop in prices of cellular phones [1]. India is the second largest mobile market in the world with more than 900 million cell phone connections and fastest growing internet market in world. A recent report by Boston Consulting Group stated that the total number of Internet users in India is expected to increase from 137 million in 2012 to 330 million by 2016 and they also noted that around 45% of online consumers in the nation use only the mobile to access the Internet and in coming years it is expected to increase up to 70% [2]. There is very little understanding of performance of cellular data connection in India. With traditional broadband internet connectivity, data connectivity provides an avenue to bridge the digital divide. It is important to understand the operating characteristics of cellular networks since the performance of the cellular networks when compared to traditional broadband network is very low [3]. Network buffer size, implementation and parameterization of transport layer protocols, latencies, radio resource management by service providers etc affects the performance of the cellular networks [4]. One reason for the lack of large-scale measurement studies on cellular networks is that researchers have limited access to cellular environments as most of the research laboratories and academic institutions do not access the Internet over cellular network [5]. We overcame this problem by our well planned measurement methodology in which we will be deploying measurement nodes across multiple locations in Rural India.

In this paper following network parameters in context of cellular data networks in India are explored i.e.:

- The throughput provided by different service providers and checked if they match the advertised bandwidth.
- Diurnal and day of week patterns are checked if any.
- Properties like RTT, DNS lookup time, network buffer sizes, etc and their effect on the network performance.
- Performance of TCP over different cellular access technologies.

These parameters help to design the strategies to optimize the performance mainly in terms of QoS and end user experience.

2. Measurement Suit Design

2.1 Measurement Methodology:

Earlier lots of manual intervention are required to conduct the experiments. So a robust model around the measurement suite is design which is entirely automated and requires minimal manual work.

2.1.1 Measurement Tests:

The Measurement suite collects parameters at transport, network, link layer and physical layer to understand how they affect the performance and help in developing strategies for optimizations

2.2 Hardware setup and Field locations:

Client (Measurement Node):

The rural locations where the measurements were to be conducted had frequent power outages and fluctuations. Netbooks provided considerable battery backup for these situations. Asus Netbook Eee PC was used as the measurement nodes.

Service Providers and USB Modems:

Network providers and the respective access technologies are selected because of their geographical coverage and their penetration into the market.

Table 1: Internet service providers, their access technology and device information

Connection	*Access Technology*	*USB Modem*
Airtel	HSDPA/GPRS	Huawei E1731
MTNL	HSDPA/GPRS	Huawei E173
BSNL	HSDPA/GPRS	Huawei E173
Idea	HSDPA/GPRS	Huawei E173
Reliance	1 xEVDO/1 xRTT	Huawei EC159

Deployment locations:

Geographical diversity has been ensured through partnership with a non-profit organization PRADAN [5]. With the help of PRADAN staff, measurements are conducted at their rural office locations. Following are the locations at which deployments had been made:

- Lamta, Dist. Balaghat, Madhya Pradesh
- Paraswada, Dist. Balaghat, Madhya Pradesh
- Ukwa, Dist. Balaghat, Madhya Pradesh
- Dindori, Dist. Dindori, Madhya Pradesh
- Samanapur, Dist. Dindori, Madhya Pradesh
- Amarpur, Dist. Dindori, Madhya Pradesh

2.3 Measurement Suite:

The robust architecture developed would help measure characteristics of GPRS/EDGE, 1xRTT, HSPA, and 1xEVDO access technologies provided by Airtel, MTNL, BSNL, Idea and Reliance and analyze the results. The measurement suite will be deployed on a netbook and installed in various locations across the country.

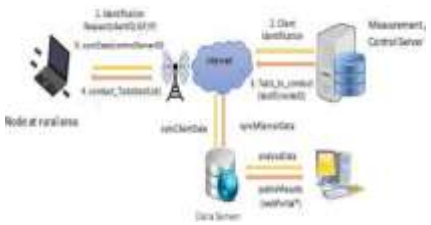

Figure 1: Architecture of the measurement suit

The measurement suite consists of four components the client, the control server, the measurement server, and the data server. The client is preconfigured with a client id and information about the service providers and corresponding access technologies to be used [6]. For each tuple of (client id, service provider, access technology), the client requests the control server for a list of tests to be conducted. The control server looks up a database to respond to the request [7]. 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.

3. Experimental Results and Analysis

The measurements for the internet service providers like Airtel, MTNL, BSNL, Idea and Reliance at five rural, one semi-urban and an urban location for a duration of three months were conducted. Important characteristics of the cellular network namely throughput, latencies and DNS lookup times are examined. Analyzing these properties is important because they affect the performance of protocols and systems running over cellular network [8].

3.1 Data rate in cellular network

From end users perspective, it is also important to know, whether the actual throughput achieved over cellular network matches the data rates advertised by the service providers.

Validation:

Tests were conducted for period of three months in 5 rural and 2 urban areas at different time of the day. Figure 2, 3, 4 and 5 shows the comparison of average downlink data rate and uplink data rate observed in 2G & 3G network versus the advertised data rates respectively.

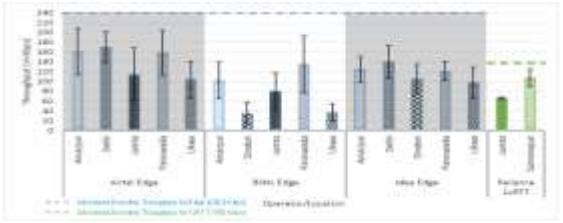

Figure 2: Downlink Throughput for various 2G operators

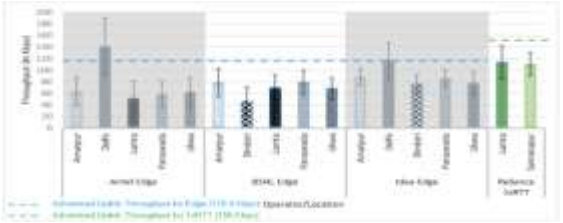

Figure 3: Uplink Throughput for various 2G operators

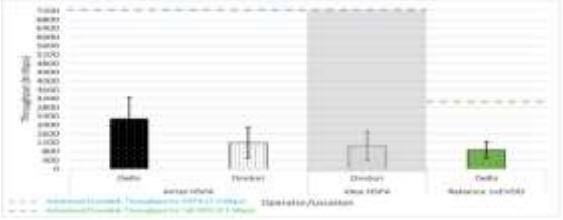

Figure 4: Downlink Throughput for various 3G operators

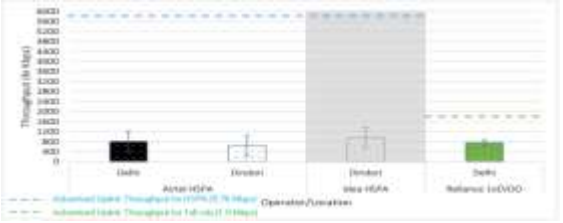

Figure 5: Uplink throughput for various 3G operators

The average Downlink & Uplink throughputs observed for 2G & 3G in various locations are significantly lower than the

protocol physical data rate except for Uplink throughput for Airtel 2G & Idea 2G in Delhi. There is high variability (standard deviation > 15% of average) in achieved throughputs at all the locations except for downlink throughput in Reliance 1xRTT in Lamta. Airtel 2G in Delhi has generally higher data rate as compared to Airtel 2G in other locations. This may suggest separate provisioning for cities compared to rural locations.

Impact:

These observed lesser achievable throughputs compared to the advertised data rates ultimately impacts the end user experience and degrades the quality of service.

3.2 Diurnal and Weekday-Weekend Patterns in Throughput:

How the time of day, day of the week impacts the TCP throughput and to see whether these patterns are present or not.

Validation:

Student's t-test is used to identify the Diurnal/Weekday-Weekend patterns. Student's t-test the actual difference between two means in relation to the variation in the data and based on the research questions, this test is used by basically stating a null hypothesis and an alternate hypothesis. Here in this case, the null hypothesis would be "There is no significant difference between the day and night patterns" and then the alternate hypothesis would be "There is significant difference between the day and night patterns" and a probabilistic value 'p' is return when $p < 0.05$ then null hypothesis is rejected.

Figure 6, 7, 8 and 9 shows the diurnal patterns in downlink and uplink throughput for 2G and 3G respectively.

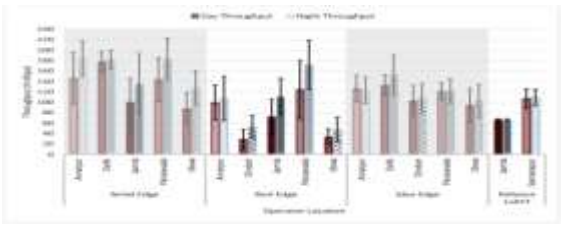

Figure 6: Diurnal pattern for downlink throughput in 2G

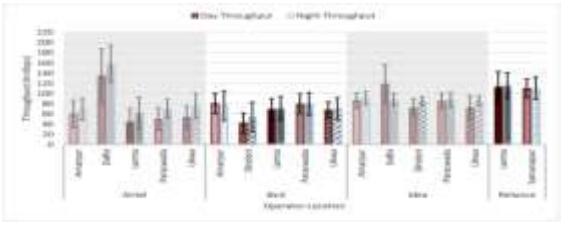

Figure 7: Diurnal pattern for uplink throughput in 2G

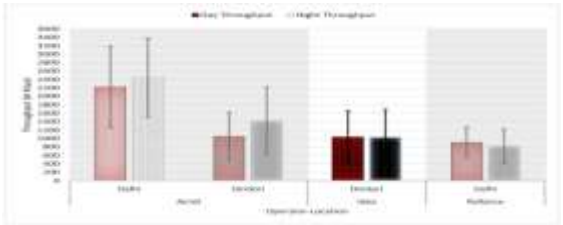

Figure 8: Diurnal pattern for downlink throughput in 3G

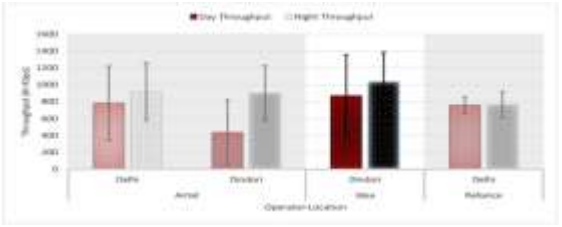

Figure 9: Diurnal pattern for uplink throughput in 3G

From the above figures it is concluded that across all rural locations in Dindori for BSNL 2G, Airtel 2G and Idea 2G, diurnal patterns in both uplink and downlink were observed and no diurnal patterns was observed in Reliance 1 xRTT.

In Delhi, Airtel 2G and Idea 2G didn't show any diurnal pattern. In Delhi and Dindori, Airtel 3G reported diurnal patterns in both uplink and downlink whereas Idea 3G reported diurnal patterns only in uplink direction in Dindori and no diurnal pattern observed in Reliance 1xEVDO.

Student's t-test reported the difference in the patterns. Through-put on weekends in Dindori was much higher than weekday in both uplink and downlink directions in BSNL 2G whereas Reliance 3G showed reduction in downlink throughput on week-ends as compared to weekdays.

Impact and suggestions:

Presence of these diurnal patterns can be exploited as:

From user's perspective: Delay tolerant application

From service provider's perspective: Incentive to the customers is provided for using internet at night time when throughput is very high.

3.3 Correlation between Signal Strength & Throughput:

One of the factors that might affect throughput is Signal Strength. Hence, it is important to know the variation of throughput with Signal Strength.

Validation:

Signal Strength values are collected using an AT command in parallel with the throughput measurements.

Table 1.1 and 1.2 shows the Pearson Correlation between signal strength and throughput values observed at different locations for various providers, in 2G and 3G respectively.

Table 2: Pearson correlation bandwidth signal strength & throughput for various 2G operators

Operator	*Place*	*Pearson Correlation For Downlink Throughput*	*Pearson Correlation For Uplink Throughput*
Airtel	Amarpur	0.09	0.01
	Delhi	0.12	0.09
	Lamta	-0.08	-0.08
	Paraswada	0.18	-0.2
	Ukwa	-0.3	-0.1
BSNL	Amarpur	0.35	0.11
	Dindori	0.17	0.01
	Lamta	-0.37	0.25
	Paraswada	0.18	0.03
	Ukwa	-0.02	0.04
Idea	Amarpur	0.37	0.07
	Dindori	0.06	-0.11
	Paraswada	0.09	0.17

	Ukwa	0.37	0.24
Reliance	Lamta	0	-0.01
	Samanapur	0.01	0.37

From above table 2 we conclude that the pearson correlation values for downlink & uplink throughput v/s signal strength for 2G operators varies from -0.3 to +0.37 for all the operators at various locations. The data indicates weak relationship between throughput of 2G operators and signal strength.

Table 3: Pearson correlation bandwidth signal strength & throughput for various 3G operators

Operator	*Place*	*Pearson Correlation For Downlink Throughput*	*Pearson Correlation For Uplink Throughput*
Airtel	Delhi	0.05	0.1
	Dindori	0.19	0.18
Idea	Dindori	0.42	0.18
Reliance	Delhi	0.01	0.02

The pearson correlation values for downlink & uplink throughput v/s signal strength for various 3G operators varies from 0.01 to +0.42 for all the +operators at various locations. The data indicates weak relationship between downlink throughput and signal strength.

Inference:
A null hypothesis that the throughput values would be affected by varying signal strength is thus contradicted by the results.

3.4 Latency in the cellular network:

One of the important factors affecting real time applications is the latency between the devices so it becomes important to study the latencies in the context of cellular networks and their impacts [9]. A list of landmark nodes for different applications distributed globally been identified for this purpose.

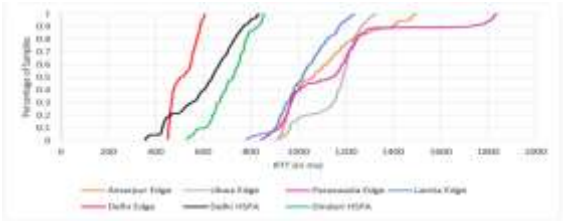

Figure 10: CDF for RTT values observed in Airtel at various locations to linode server**.**

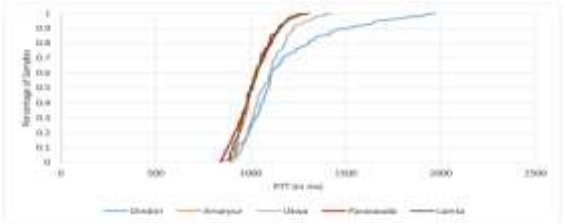

Figure 11: CDF for RTT values observed in BSNL at various locations to linode server.

From Figure 10 and Figure 11, significantly high ping RTTs can be observed to many landmark nodes including the ones known to be in India; about 80% of measurements reported RTT in the range of 600ms - 1200ms in Airtel 2G and BSNL 2G in rural areas. Airtel 3G in Dindori and Delhi along with Airtel 2G in Delhi reported RTTs of less than 800ms for 80% of the measurements. This is significantly high compared to commonly expected latencies in 2Gand 3G networks. Also, Airtel 2G in Delhi reported lesser RTTs than Airtel 3G in Delhi.

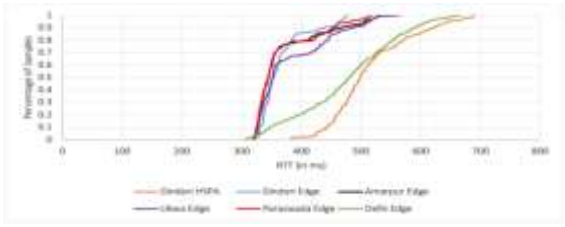

Figure 12: CDF for RTT values observed in Idea at various locations to linode server.

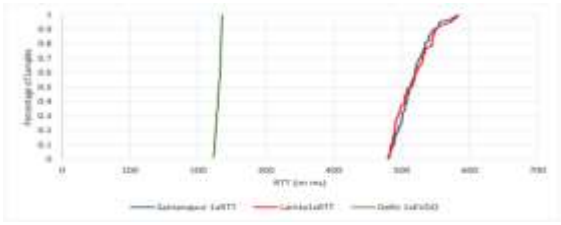

Figure 13: CDF for RTT values observed in Reliance at various locations to linode server

Figure 12 and Figure 13 shows that 60% of the measurements reported RTTs less than 550ms in Reliance and Idea in 2G in rural areas and less than 250ms in Reliance 3G in Delhi. Also, Rural locations where Idea 2G was deployed showed significantly less RTTs than in Delhi 2G and Idea 3G in Dindori which reported similar RTTs. Idea 3G in Dindori reported largest of the RTTs among all the locations where Idea was deployed.

RTT observed in Idea were significantly lower than other service providers. This matches well with the low DNS lookup time observations discussed later. RTT in Airtel 2G is significantly lower than in other places. It indicates that high RTTs are likely due to network configuration rather than protocol properties.

Impact:
Having large RTT degrades the user experience and it also affects real time application (voice applications). In such cases, applications that use Voice over IP, multimedia streaming etc, would perform ineffectively.

3.5 Content Hosting in the Service Providers:

www.ebay.in,www.ndtv.com,www.espncricinfo.com,www.timesofindia.com was found to be hosted by the popular CDN Akamai Technologies [10]. These sites were also found to have their content hosted within the service provider's network for all the service providers except in Airtel. IP lookup of trace route data using who is resolved to either the service provider or Akamai.

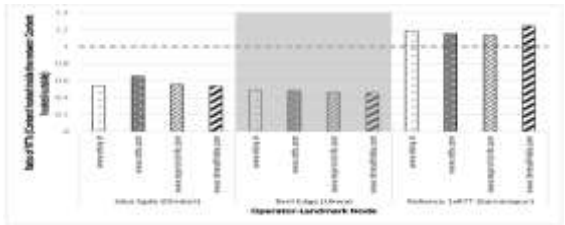

Figure 14: Ratio of RTTs for content hosted in inside the network v/s outside the network

A comparison between the RTTs when the content was hosted within the service provider and when it was hosted outside

showed remarkable difference of ~50% in BSNL and Idea (both 2G and 3G) in rural locations as shown in Figure 14 while Airtel showed only slightly lesser RTTs. Reliance in rural areas on the other hand reported RTTs being lesser when the content was hosted outside the network. Student t-test was conducted to confirm the difference observed was indeed statistically significant ($p<0.05$).

3.6 Latency over wireless link:

We could not identify contribution of the wireless hop to overall latency because trace route statistics showed ratio of RTT to GGSN to RTT to our server as >= 1. This indicates that the task of sending an ICMP back (as required in trace route) is given lower priority on GGSN. Similar observations were made across all the landmark nodes.

3.7 Diurnal and weekday-weekend patterns in RTTs:

In this section, we try to understand how the time of day, day of the week impacts the latencies and to see whether these patterns are present or not. Figure 15 shows the ratio of the RTTs observed during night with the RTTs observed during day for BSNL Edge in various locations.

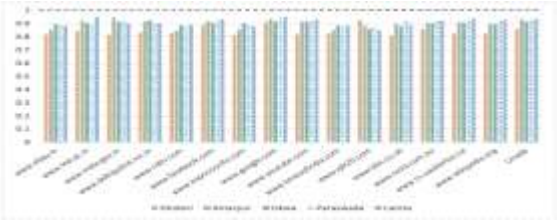

Figure 15: Diurnal pattern ratio (Night:Day) in BSNL at various locations

Student t-test with $p<0.07$ confirmed BSNL showing diurnal pattern in latencies across all locations. However, No weekday-weekend patterns were found for any of the landmark nodes across all locations for all the service providers.

3.8 DNS and lookup times:

From the end user perspective, it is important to know the contribution of DNS lookup to the overall web object retrieval time.

Validation:
In the DNS lookup test, query of the DNS server for looking up IP address of the domain name (www.iitd.ac.in) using a tool Dig were made. The test is performed periodically in a day over a period of 3 months for all the operators across various locations. Figure 16 and figure 17 shows the average lookup times for all the operators across locations.

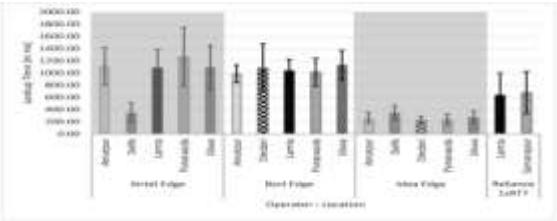

Figure 16: Average lookup times at various locations for 2G

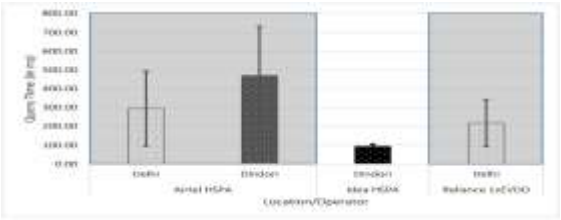

Figure 17: Average lookup times at various locations for 3G

- In 2G connections, Idea in all the locations had significantly lower DNS lookup time compared to other providers. Airtel 2G in Delhi had significantly less lookup time as compared to Airtel 2G in other rural locations. This is another indication (in addition to better throughputs and RTTs), that Airtel 2G has provisioned to provide better service in Delhi compared to other rural areas.
- Even in 3G, Idea outperforms Reliance, Airtel Delhi and Airtel Dindori. Airtel 3G in Delhi has better lookup times compared to Airtel Dindori, again indicating better provisioning for the city.

Other Observations:

- All service providers use two DNS servers except BSNL which uses three.
- Idea allotted different DNS servers for Delhi and Madhya Pradesh, which may mean that the DNS server allocation is done based on location/region of the client.
- Also, Airtel was observed to be using Google DNS (8.8.8.8) server on a day at two locations during same time (Information about other locations not available at that time). This may indicate use of Google DNS either as a backup or an offloading server when its own servers are overwhelmed.

Impact:

- The large DNS lookup time for Airtel, BSNL and Reliance in rural areas adds an overhead to the overall web object retrieval time.
- The lower DNS lookup time in Idea 2G and Idea 3G increase the performance of short lived TCP flows.

3.9 Radio Resource Management Test:

Base stations normally put devices that are not active in idle state to conserve battery power of the device and to utilize radio resources better. The time of inactivity after which a device is put in idle state and the time it takes to return to active state can impact end user experience [11].
Validation:
Based on the algorithms proposed in Appendix A, tests were conducted across three ISPs. The initial state indicated in state transition figures 18 through 19 is the state of the dongle upon connection initialization. Note that the initial state is different from idle state.
There are three states described as:

- DCH – data transmission in dedicated channel, where user gets higher bandwidth with high radio usage.
- FACH– data transmission in forward access channel, where user gets lower bandwidth with low radio usage.
- IDLE – no data transmission and no radio power.

The access technologies associated with these states along with the time and/or size based events upon which state transition takes place are presented below for Airtel, MTNL and Reliance.

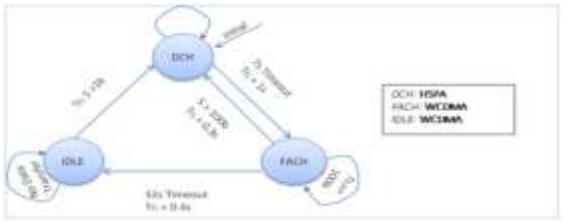

Figure 18: State Transition Diagram for Airtel HSPA

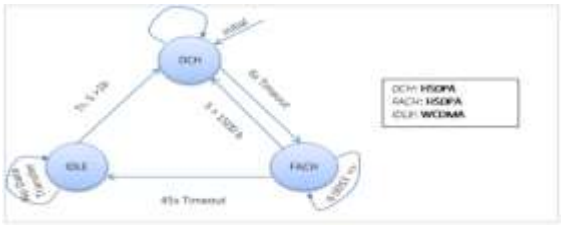

Figure 19: State Transition Diagram for MTNL HSDPA

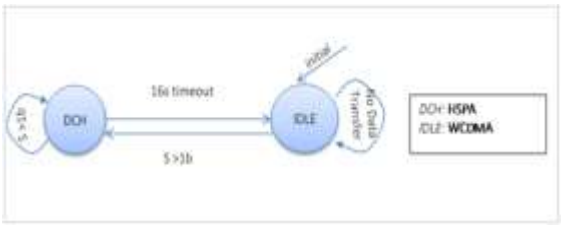

Figure 20: State Transition Diagram for Reliance HSPA

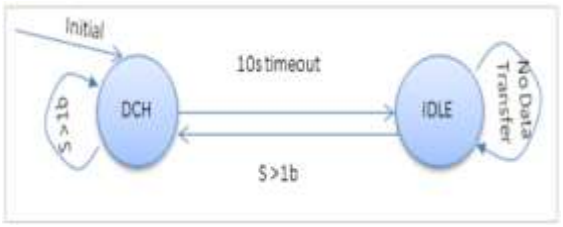

Figure 21: State Transition Diagram for Reliance EVDO

All the state transitions, for all the providers reported static based event triggers. Airtel and MTNL reported 3 states while Reliance reported only 2 states

Impact:
Current design of RRC State machine is static, which can be made dynamic based on past user activity and identifying intrusions to provide a better user browser experience.

3.10 Some application layer tests:

In addition to the periodic tests, a few one-time tests like testing the existence of NATs, HTTP proxies, and web caches in the service provider networks were done. Netalyzr was used to conduct some of the tests.

- No NAT was found in Airtel, BSNL and Reliance. All IP address assignments across all providers were public. However sometimes, Idea was found to use carrier grade NAT with IP range 100.64.0.0/10 making it inaccessible from outside the network.
- Files with virus signature from well-known EICR site for all the providers were downloaded and it was found that none of the service providers had inbuilt network antivirus protection implemented.
- In Airtel, UDP access to remote DNS servers (port 53) seems to pass through a firewall. DNS lookup works fine, but non-DNS traffic on port 53 seems to get blocked.
- All service providers had DNS support for IPv6, but none of them supported IPv6 connectivity.
- Idea blocks direct access to port 5060, thus limiting usage of Session Initiation Protocol (SIP) client.
- No HTTP proxy or web cache was detected in any operator.
- All service providers seem to load balance GGSNs. We discovered 3, 5, 4, and 2 GGSNs for Airtel, BSNL, Idea, and Reliance respectively.
- There seems to be location based GGSN allocation in Idea. Out of 4 GGSNs, 2 were observed only on the Delhi client, and the other 2 were observed in all locations exception Delhi.
- Airtel seems to allocate additional resources to service 3G clients in Delhi. One of the 3 GGSNS was observed at all locations, but, the other two seem to be used only in Delhi's 3G connections.

So, important characteristics of the cellular network namely throughput, latencies and DNS lookup times are examined and analyzing of these properties is important because they affect the performance of protocols and systems running over cellular network.

4. Conclusion

In this paper following tasks and findings have been achieved i.e. Design of automated rural internet measurement suite, Comparing the data rates advertised by different service, Understanding the impact of time of day on TCP throughput, Understanding the factors for low achieved throughput. sLower throughputs are caused by long periods of inactivity in TCP flows, which we call long flow gaps, which in turn seem to be related to burstiness of the flows, Comparing the Internet in Rural and Urban areas and the Impact of placing content within the service provider network.

To further understand the characteristics of the network more tests can be done to find the long flow gaps and to come up with an effective dynamic algorithm to avoid them, study can be done to know the effects of filling of buffers on latency (uplink and downlink), Detection can be done to know that if any traffic shaping is done by the service providers and also to understand the type of internet traffic in rural areas and Large scale deployment of the suite in various locations can be done in future to better understand the network characteristics.

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Author Profile

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