Main Observations (as filed):

a) Tasks on observed 2G speeds can theoretically take up to 50 times longer than they would on observed 4G speeds.

b) As a security best-practice, the Open Web Application Security Project recommends setting the server timeout to the minimal possible value based on the context of the application. In addition, intermediaries and clients impose timeouts on connections too. There is no universal value for these settings. The higher the time required to download content, the greater is the likelihood of such timeouts being encountered.

c) Video streaming and Video conferencing/communication services should be expected to perform poorly on 2G speeds, as observed 2G network conditions are well below the minimum requirements published by leading video streaming / video communication platforms like YouTube, Zoom and Skype.

d) Simulated tests for select use-cases took up 37 times longer on 2G speeds than they did on 4G, if they worked at all. This ratio may increase in real world scenarios once congestion, packet-loss, signal strength etc are accounted for. Some interactive interfaces like the World Health Organization's Situation Tracker did not function at Observed 2G speeds.

e) Based on YouTube as a test case, video playback was subject to significant degradation with videos taking up to 60 times longer to start playback and experiencing up to 3.8s of buffering for every 1 second of playback i.e. a 20 minute video could take up to 1 hour and 36 minutes to watch completely.

Implication of 4G and 2G connection speeds on web performance

Prateek Waghre

Abstract

The network speed available to a user i.e. 2G or 4G plays a highly significant role in determining how quickly/slowly they are able to complete their objectives or whether they are able to complete them at all. This document includes a theoretical comparison between 2G and 4G network speeds in the context of common tasks on the internet and a qualitative assessment of the effect that 2G can have on video streaming (broadcast) and video conferencing (interactive) applications. It also includes the results of a simulated performance comparison for selected use-cases to demonstrate the extent to which lower network speeds adversely impact the time taken by a person to successfully complete routine tasks over the internet.

4G v/s 2G speeds in India

As per TRAI [1],

> *"4G stands for the fourth generation of mobile connection speeds. 4G or LTE is upgraded mobile data technology that provides extremely high download data speed upto 150 Mbps and advanced LTE can provide download speeds upto 300 Mbps. Voice call service in LTE is provided over data/packet network (VoLTE- voice over LTE) unlike 2G/3G, where circuit switched network is used to make voice calls."*

And

> *"2G or GSM is a digital mobile technology that provides voice call service & data services with download speed upto 384 Kbps."*

The download speeds listed above are theoretical values. In practice, the speed available to users will be a function of network coverage/deployment, congestion and allocation/availability

[1] TRAI Myspeed portal - FAQ ; https://myspeed.trai.gov.in/faq.php

of spectrum. Based on reports from Ookla[2] and OpenSignal[3], which measure samples from across India, a representative set of 4G parameters can be estimated for analysis[4].

2G speeds and latency are no longer specifically measured by either Ookla or OpenSignal. The latter, in a report dated April 2017 [5] stated:

> *"(We exclude 2G as 2G results vary little from operator to operator and generally don't provide enough bandwidth for an adequate mobile data experience) "*

TRAI also explicitly filters out 2G log lines as mentioned in its Whitepaper on Measurement of Wireless Data Speeds [6]. Joint-research conducted by CUTS and IIT Delhi[7] provides parameters which can be used as representative values for analysis[8]. It is also worth noting that Ookla has published an analysis indicating a slight downward trend in network speeds due to COVID-19[9].

The following can be considered to be representative[10]:

4G

- Download Speed : 9.8 Mbps
- Upload Speed : 2.9 Mbps
- Latency : 60 ms

Hereafter referred to as Observed 4G Download Speed / Upload Speed / Latency

2G

- Download Speed : 168 kbps
- Upload Speed : 100 kbps
- Latency : 310 ms

Hereafter referred to as Observed 2G Download Speed / Upload Speed / Latency. The theoretical speed of 384 kbps is hereafter referred to as Peak Theoretical 2G Download Speed.

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[2] Ookla India Data : https://www.speedtest.net/global-index/india
[3] India Mobile Network Experience, April 2020 : https://www.opensignal.com/reports/2020/04/india/mobile-network-experience
[4] While these parameters will vary across the country, the listed values can be considered to broadly representative
[5] State of Mobile Networks - India (April, 2017) : https://www.opensignal.com/sites/opensignal-com/files/data/reports/national/data-2017-04-india/report.pdf
[6] Page, 25 : https://myspeed.trai.gov.in/WhitePaper_measurement_wireless_data_speed.pdf
[7] CUTS (2016), IIT Delhi, Mobile Internet Services in India: Quality of Service, CUTS, Jaipur : http://www.iitd.ac.in/research/IITD/1615_QoS_Report_CUTS_IIT.pdf
[8] Refer to 4
[9] Speedtest, Tracking Tracking COVID-19's Impact on Global Internet Performance https://www.speedtest.net/insights/blog/tracking-covid-19-impact-global-internet-performance/
[10] Refer to 4

State of the Web

httparchive's State of the Web report has analysed nearly 10 million URLs and published the following observations regarding Desktop and Mobile URLs as of March 1 2020 [11].
Table 1 includes 75th percentiles ; i.e. 75% of measurements will fall within the values listed. 25% or 1 of every 4 samples will have corresponding values higher than those represented in the table.

Definition of parameters listed (as per httparchive reports):

- Total Kilobytes : *The sum of transfer size kilobytes of all resources requested by the page.*

- Total Requests : *The number of resources requested by the page.*

- Image Bytes : *The sum of transfer size kilobytes of all external images requested by the page.*

- Image Requests : *The number of external images requested by the page.*

- DOMContentLoaded : *The number of seconds from the time the navigation started until the initial HTML document has been completely loaded and parsed, without waiting for the stylesheets, images and subframes to finish loaded.*
  Typically, a number of elements on the page are visible by this point however the page may or may not be usable. That is dependent on page design and browser rendering

- onLoad : *The number of seconds from the time the navigation started until the document and all of its dependent resources (images, stylesheets etc) have finished loading.*
  Note that a page typically becomes usable/interactive (Time to Interactive) some time in between DOMContentLoaded and OnLoad events. Time to Interactive implies that some of the functionality on a page is now available - it is a non-standardized web performance metric. It does not mean that a page is fully functional, that can vary based on website design and browser performance.

[11] httparchive, State of the Web, https://httparchive.org/reports/state-of-the-web?start=2019_08_01&end=latest&view=list

Table 1: Page parameters derived from httparchive State of the Web report.

Parameter (Percentile)	Mobile	Desktop
Total Kilobytes (p75)	3624.7	3987.7
Total Requests (p75)	114	120
Image bytes (p75)	2362.1 Kilobytes	2529 Kilobytes
Image Requests (p75)	48	53
DOMContentLoaded (p75)	7.4 seconds	2.9 seconds
onLoad (p75)	30.9 seconds	10.7 seconds

Based on Total Kilobytes in Table 1 and observed 4G and 2G (+ peak theoretical 2G) download speeds, it is possible to estimate the expected time to download a page and its resources. [12]

Table 2 : Theoretical comparison of page download times from Table 1.

4G (Observed Download Speed)	2G (Observed Download Speed)	2G (Peak Theoretical Download Speed)
Mobile [13] : 2.96s	Mobile [14] : 2 mins 52s	Mobile : 1 min 15.5s
Desktop [15] : 3.25s	Desktop [16]: 2 min 59s	Desktop : 1 min 23s

[12] Refer to 16.
[13] 3624.7 KiloBytes (KB) = 28,997.6 Kilobits (Kb) (1 Byte = 8 bits). 28,997.6 Kb / 9.8 * 1000 Kbps = 2.95 seconds.
[14] 3624.7 KiloBytes (KB) = 28,997.6 Kilobits (Kb) (1 Byte = 8 bits). 28,997.6 Kb / 168 kbps = 172.6 seconds.
[15] If using a hotspot; From 12 Replace 3624.7 with 3987.7
[16] If using a hotspot; From 13 Replace 3624.7 with 3987.7

Table 3 : Theoretical comparison of image download times from Table 1.

4G (Observed Download Speed)	2G (Observed Download Speed)	2G (Peak Theoretical Download Speed)
Mobile : 1.93s	Mobile : 1 min 53s	Mobile : 49.21s
Desktop : 2.06s	Desktop : 2 mins	Desktop : 52.69s

Table 4: Theoretical comparison of download times for a 5 MB file.

4G (Observed Download Speed)	2G (Observed Download Speed)	2G (Peak Theoretical Download Speed)
4.08s	3 mins 58s	1 min 54s

Inference(s) :

1. At Observed 2G download speeds, the same task **could take upto 50x longe**r than at Observed 4G download speeds.[17]
2. At Peak Theoretical 2G download speeds, the same task **could take upto 25x longer** than at Observed 4G download speeds.[18]
3. As a security best-practice, OWASP recommends[19] setting the server timeout to the minimal possible value based on the context of the application. In addition, intermediaries and clients impose timeouts on connections too. There is no universal value for these settings. The **higher the time required to download content, the greater is the likelihood of such timeouts being encountered**.

[17] This is meant to be indicative. It does not take into account the time taken for multiple requests to traverse back and forth over the internet and any processing time at the origin server. As 4G latency is 1/6th of 2G latency, the high ratios will hold even when that is taken into account.

[18] Refer to 16.

[19] OWASP (Open Web Application Security Project) Community , https://owasp.org/www-community/Session_Timeout

Audio / Video Streaming and Delivery

At a high-level, Audio-Video content delivered over the internet can be divided into 2 categories

1. **Audio / Video Streaming (Broadcast)**

General purpose video content such as those available on platforms like YouTube, On-Demand e-learning content , Netflix, HotStar, Live streaming of news content, speeches made by the Prime Minister, etc. all fall under this category. Today, such content is most commonly delivered via protocols like Apple's HLS (HTTP Live Streaming) and MPEG-DASH (Motion Picture Experts Group - Dynamic Adaptive Streaming over HTTP). These protocols enable ABR (adaptive bitrate streaming) which is the ability for the video quality to be changed in accordance with the bandwidth available at a user's device.

It can also be delivered as a progressive media download or a single file download.

The QoS (Quality of Service) metrics typically used are startup time[20], lag or re-buffer ratio[21] and frame loss[22]. These metrics require advanced analytics so a quantitative analysis of video performance on 2G v/s 4G cannot be made in the same way as the previous (and following) section.

Some qualitative inferences can be derived based on the system requirements published by Youtube[23] and Netflix [24]. These companies have been selected as examples because they are consistently at the fore-front of streaming technology and video delivery at scale, and not for the nature of content they may or may not provide.

A) Youtube

Video Resolution	Recommended sustained speed
4K	20 Mbps
HD 1080p	5 Mbps
HD 720p	2.5 Mbps
SD 480p	1.1 Mbps

[20] Time taken for playback to start, also known as buffer fill.
[21] Ratio of time spent waiting for video playback to time spent watching the video.
[22] Video frames dropped.
[23] System Requirements, https://support.google.com/youtube/answer/78358?hl=en
[24] Internet Connection Speed Recommendations, https://help.netflix.com/en/node/306

SD 360p	0.7 Mbps

B) Netflix

... internet download speed recommendations per stream for playing TV shows and movies through Netflix.

- *0.5 Megabits per second - Required broadband connection speed*
- *1.5 Megabits per second - Recommended broadband connection speed*
- *3.0 Megabits per second - Recommended for SD quality*
- *5.0 Megabits per second - Recommended for HD quality*
- *25 Megabits per second - Recommended for Ultra HD quality*

Inference

- It should be noted that even the lowest recommended settings are higher than both the Observed 2G speed and Theoretical Peak 2G speed. Thus video viewing experience will be **subject to significant degradation compared to 4G speeds**.

2. Audio / Video Conferencing (Interactive)

Video Conferencing services like Zoom, Cisco Webex, Skype, Interactive elearning classes, VOIP, WebRTC etc. would fall in this category.
In such applications, in addition to the bandwidth or speed, network latency, jitter and packet loss are important QoS metrics.

Zoom lists the following bandwidth requirements for mobile devices [25]

The bandwidth used by Zoom will be optimized for the best experience based on the participants' network. It will automatically adjust for 3G or WiFi
Recommended bandwidth over WiFi:

- *For 1:1 video calling: 600kbps (up/down) for high quality video and 1.2 Mbps (up/down) for HD video*
- *For group video calling: 600kbps/1.2Mbps (up/down) for high quality video. For gallery view: 1.5Mbps/1.5Mbps (up/down).*

Skype recommends (download/upload):

- For 1:1 High Quality calling : 500 kbps / 500 kbps
- For 1:1 HD Quality calling : 1.5 Mbps / 1.5 Mbps

[25] Zoom - System Requirements, https://support.zoom.us/hc/en-us/articles/201179966-System-Requirements-for-iOS-iPadOS-and-Android

- Group (3 people) : 2 Mbps / 512 Kbps
- Group (7+ people) : 8 Mbps / 512 Kbps

Facebook / Whatsapp have not published bandwidth recommendations for VOIP and Video calls.

For the other parameters, acceptable values are [26]

- Latency : < 150 ms
- Jitter : 10-50 ms
- Packet Loss : 0.5-1%

Currently, no representative values for Jitter and Packet Loss are available for 2G in India.

Inference

- Comparing the **available recommendations** for bandwidth and latency with Observed 2G speed and latency indicates that **users will face significant issues when using video conferencing applications**. These **issues will be exacerbated by multitasking**, as expected in the current scenario.

[26] Cisco, Transport network SLAs, https://www.cisco.com/c/en/us/support/docs/quality-of-service-qos/qos-video/212134-Video-Quality-of-Service-QOS-Tutorial.html#anc11

Simulated Comparison between 2G and 4G

Objective:

In order to estimate how the difference in Observed 2G speed and Observed 4G speed may translate into practice, simulated tests were run for a few selected use-cases. [27]

Testing Methodology

In order simulate the Observed 2g and 4G network speeds the following methods were used:

1) Charles Proxy[28]

Charles is an HTTP Proxy that makes it possible to view all HTTP and in some cases HTTPS requests between a machine and the internet. It also has a 'Throttle' setting that was programmed with the Observed 2G and 4G speeds. Requests were made through an iPhone 5s which was proxied through Charles to enforce the speed conditions. This method was used for use-case 1.

2) Chrome Developer Tools

Google Chrome's built-in Developer Tools also provide the ability to simulate a mobile device and network conditions. These were programmed with the Observed 2G and 4G speeds. This method was used for use-cases 2-7.

Note :

- While these methods can simulate the speed restrictions accurately, they may not reproduce the consequences of network congestion, packet loss, low signal strength that end-users may encounter in practice. These issues will affect 2G performance to a larger extent than they would impact 4G performance.
- The tests were run multiple times to weed out any outliers. Representative results have been used.

[27] 2G network at the author's location could not even run a standard speedtest while 4G network indicated a speed of 21 Mbps, thus would not represent a meaningful comparison. Therefore observed 2G and 4G network speeds from the previous section were used.

[28] Charles - https://www.charlesproxy.com

Test Cases

Table 5: Comparison of time taken on 2G v/s 4G

Sl. No.	A. Test Case	B. Time taken on Observed 4G speeds	C. Comments	D. Time taken on Observed 2G speeds (*in multiples of B)*
1.	Download Arogya Setu App (23.6 MB)	2 min 25s		**11x**
2.	Sample 12 MB File [29]	24s		**24x**
3.	Access MOHFW website[30]	1s (DCL) * 2.9s (PL) **		**24x** (DOM) **20x** (PL)
4	Sample PDF from MOHFW Website (5.8 MB) [31]	5s		**54x**
5	WHO International website [32]	4s (DCL) 8s (PL)		**27x** (DOM) **22.5x** (PL)
6	WHO Situation Dashboard[33]	1.58 (DCL) 1.6 (PL)	*Dashboard did not load visually on 2G*	NA - **Dashboard did not work on 2G**
7	COVID-19 Awareness Image on Twitter[34]	1.5s		**37x**
8	Vedantu - Home Page[35]	2.2s (DCL) 4s (PL)		**16x** (DCL) **31.5x** (PL)
9	Upload 12 MB File (WeTransfer)	37s		**26x**
10	JK Motor Vehicles Dept	12.5s (DCL) 13s (PL)		**21x** (DCL) **19x** (PL)
11	Youtube Home Page	1s (DCL)		**26x** (DCL)

[29] https://eoimages.gsfc.nasa.gov/images/imagerecords/49000/49958/pacific_goe_2011079_lrg.jpg
[30] https://mohfwa.gov.in
[31] https://www.mohfw.gov.in/pdf/NBTCGUIDANCEFORCOVID19.pdf
[32] https://who.int
[33] https://who.sprinklr.com/
[34] https://pbs.twimg.com/media/ESWEFtFU4AENWAX?format=jpg&name=4096x4096
[35] https://www.vedantu.com/

		1.8s (PL)		**25x** (PL)
12	Youtube Sample Video Playback 1[36]	1s (DCL) 2.2s (PL) Video Start 1s -near instant Playback at 480p: No buffering Playback at 360p: No buffering		**35x** (DCL) **21x** (PL) Video start **60x** Playback at 480p: Significant buffering. *For every 1s of playback, there were 1.2s of buffering.* Playback at 360p: Significant buffering. *For every 1s of playback, there were 0.7s of buffering.*
13	Youtube Sample Video Playback 2[37] (Action scene)	1s (DCL) 2.6 (PL) Video Start 1s - near instant Playback at 480p: No buffering Playback at 360p: No buffering		**26.5x** (DCL) **17x** (PL) Video start **52x** Playback at 480p : Extremely significant buffering. *For every 1s of playback there were 3.8s of buffering..* Playback at 360p: Very significant buffering. *For every 1s of playback there were 2.3s of buffering.*
14	10-12s Video upload on Whatsapp	43s		**27x**

* DCL - DOMContentLoaded event
** PL - PageLoad or OnLoad event

[36] https://youtu.be/IJoXu0k4fIU (MHOFW Awareness Video)
[37] https://m.youtube.com/watch?v=GSrtUVzdt6M

Observation(s)

- Tasks on **Observed 2G speeds took 11 - 37 times longer than they did on Observed 4G** speeds in the simulated environment. This ratio may increase in real world scenarios once congestion, packet-loss, signal strength etc are accounted for.
- Some **interactive interfaces** like WHO's Situation Tracker **did not function at Observed 2G speeds**.
- Video playback on Observed 2G speeds faced significant degradation compared with Observed 4G speeds. **Playback was near instant at Observed 4G speeds but took upto 60x longer on Observed 2G speeds.** There was also significant buffering at Observed 2G speeds, depending on the nature of video (high-action v/s low-action) and resolution playback was constantly interrupted by buffering. **For every 1s of video watched there was 0.7 to 3.8s buffering. i.e. a 20 minute video could end up taking anywhere from 34 minutes to 1 hour 36 minutes to watch completely.**