Integrated Satellite Terrestrial Networks: A GEO-based Resource Provisioning Use-case

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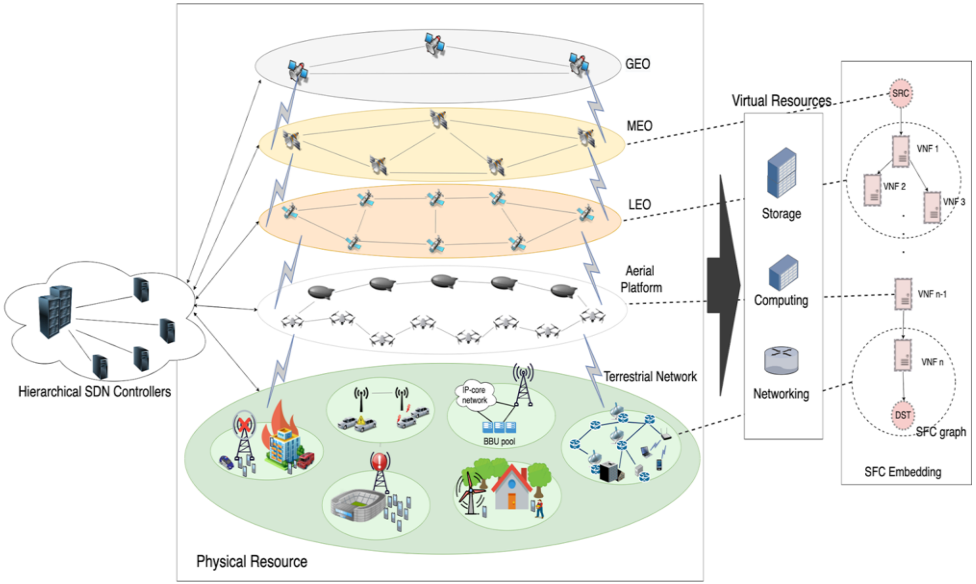
Motivation

- Huge amounts of data are available in high speed (fiber) server networks. Effective utilization of these data (the digital transformation) will change every aspect of work, life, society. Further we are moving fast towards a networked immersed world (the metaverse)
- However, access to these data is limited to no more than 15% to 20% of populations world-wide – accepting great heterogeneity from country to country and geographic regions
- The pandemic demonstrated that without widely available broadband access to these data, and the services they enable, we cannot have democratized education, healthcare, manufacturing, environmental monitoring, jobs, housing, food and water resources ...
- As we plan future communication infrastructures involving 5G, 6G, NextG, we must consider the implementation cost . It is clear that it is impossible to provide such access to many regions of the earth via fiber. Broadband communications must be provided to all, in the same way we provide transportation roads to all, regardless of where they live
- To accomplish these high impact goals, we must eliminate digital divide as much as possible. This simple observation leads us to consider hybrid communication technologies combining terrestrial and non-terrestrial means. They are definitely more cost-effective. But we need to carefully investigate the requirements of typical applications in terms of delay and bandwidth requirements in order to be able to dynamically (slicing) provide the required resources to the maximum number of people at affordable costs.

SDN-Enabled Satellite Air Ground Integrated Network (SAGIN)

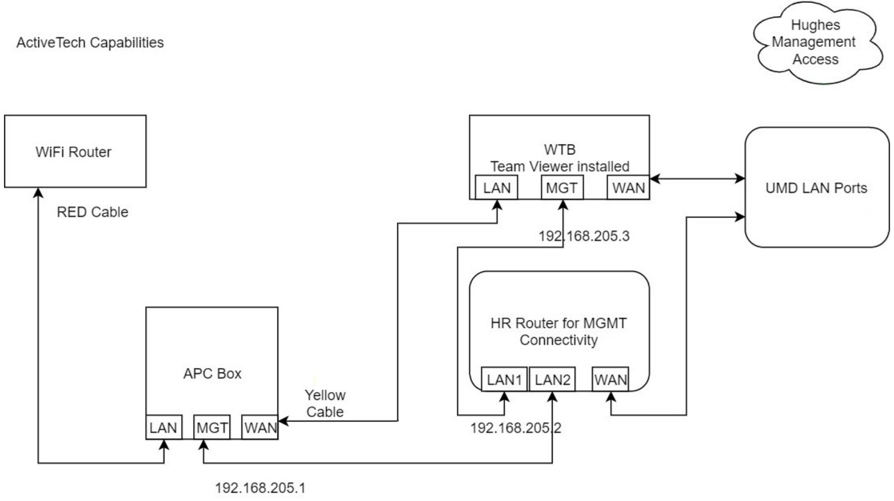


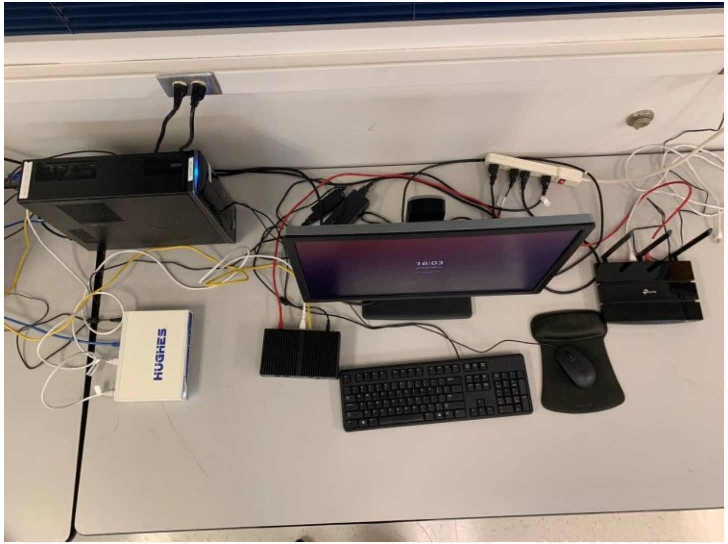
Towards achieving the 5G key promises, it is essential to utilize the capacity of all sorts of communications networks (terrestrial, space, aerial) and supporting technologies (SDN, NFV, etc.) simultaneously, as opposed to the traditional standalone fashion.

Use-case Experiments

- Various governments have recently introduced Infrastructure Bills providing funding to make Broadband Services available to most people. Unfortunately, the funding is not adequate and often the requirements in delay and bandwidth do not represent experimental evidence of widely used applications (i.e., often require excessive response speed and bandwidth).

- A key aspect of providing broadband services to max number of people at affordable cost/prices is the detailed understanding and quantification of the response delay and bandwidth requirements of commonly used Internet applications, specifically the low-latency throughput requirements.





HTACT Simulated Networks

- HTACT should gather a set of measurement for each of the following simulated broadband networks:
- INFRA (Infrastructure Bill Broadband Specs) – 100 Mbps down, 20 Mbps up, 100 ms latency, 0 packet loss and jitter
- HTSP (High-Throughput geostationary orbit –GEO– Satellite PEP'ed) – 100 Mbps down, 20 Mbps up, 700 ms latency, 0 packet loss and jitter
- We combine the HTACT measurements with selected sets of applications to determine a typical residence's Bulk (Satellite) and Interactive (Terrestrial Wireless) throughput requirements

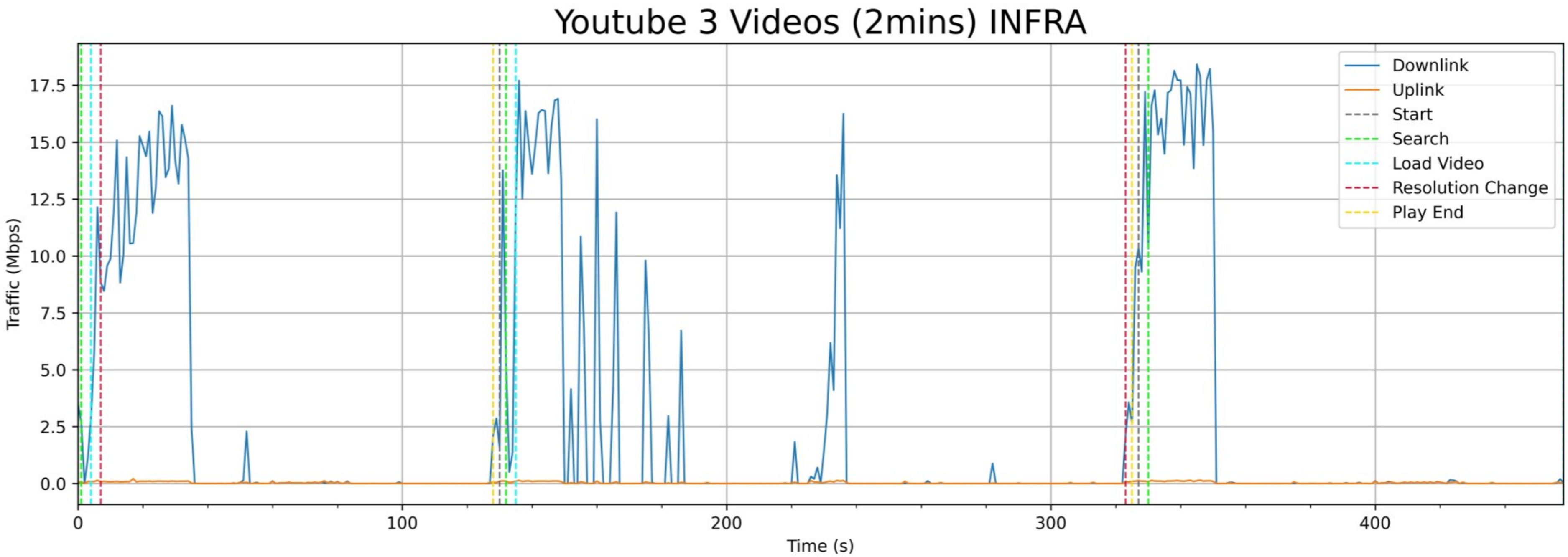
Setup for Experiments

- We created Python scripts for the automation of the functionalities:
  - Searching,
  - Loading,
  - Playing videos,
  - Adapting resolution

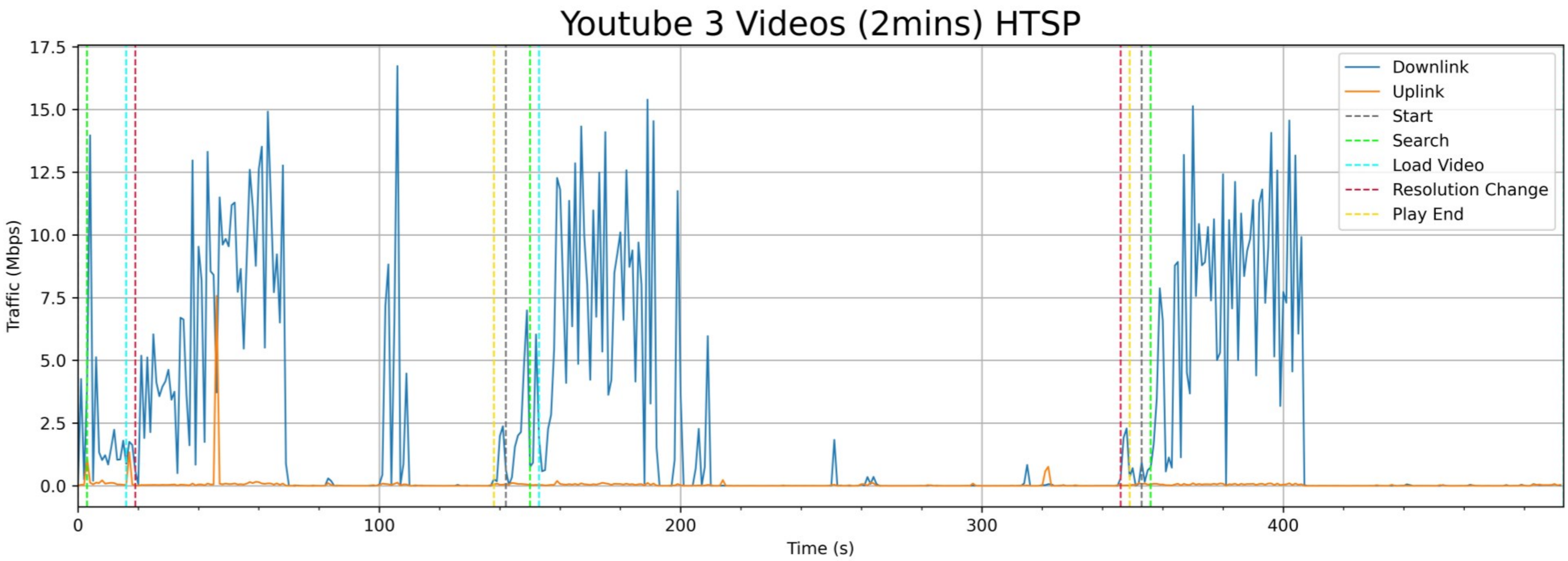
  when testing applications such as YouTube and Netflix

- The modular design of the scripts along with timestamps saving allows for easy matching traffic captured via Wireshark
- Each functionality is mapped to its generated traffic based on its timestamps
- The Layer 3 traffic data is then processed for the data usage analysis

Youtube Script Demo



Video / Second	Start	Search	Load Page	Resolution Change	Play End Times
1	0	1	4	7	128
2	128	130	132	135	323
3	323	325	327	330	458



Video / Second	Start	Search	Load Page	Resolution Change	Play End Times
1	0	3	16	19	138
2	138	142	150	153	346
3	346	349	353	356	493

Non-/Interactive Step Classification for YouTube

Step	Peak Downlink Throughput (Mbps)	Peak Uplink Throughput (Mbps)	Class
Search	3.95	1.13	Interactive
Load Page	7.50	0.44	Interactive
Resolution	11.79	0.36	Bulk
Play	16.81	0.81	Bulk

Video MOS (VMOS) Scale

Quality	**VMOS (Score)**	**Definition**
Excellent	5	Excellent session quality, no noticeable audio or video errors
High	4	Very good session quality, very few video freezes or dropped/garbled audio
Medium	3	Moderate session quality, multiple video freezes and/or dropped/garbled audio, but can still follow the session
Low	2	Low session quality, frequent audio/video issues. Very difficult to conduct session
Poor	1	Poor session quality, unable to conduct audio/video session

LTE Throughput Requirements

- What is the minimum INFRA (LTE) downlink throughput link capacity we can achieve while preserving a respectable Mean Opinion Score (MOS)?
- Similar question for the INFRA uplink throughput capacity can be asked
- The NTIA broadband definition stipulates that the total throughput provided to the customer be 100Mbps/20Mbps, but a HTS-INFRA hybrid architecture can set the INFRA component throughput requirements for the interactive steps even lower
- We experiment with various configurations of $(\texttt{upthru},\texttt{dnthru}) \in \mathbb{N}^2$
    - e.g., -upthru=20000000 -dnthru=100000000
- We lower the throughput parameters until the MOS reaches 3
- We do not explore channel capacity that yields low or poor MOS

MOS for YouTube and Summary

Downlink Capacity (Mbps)	Uplink Capacity (Mbps)	MOS
10	10	5
5	2	4
3	3	3

HTSP VMOS	LTE MOS	LTE DL Required Throughput	LTE UL Required Throughput
5	4	5Mbps	2Mbps

Netflix

Steps:

1. Logging in and searching for the first title
2. Preview and loading the first title
3. Steady state playtime for the first title (1 min)
4. Back to the main menu and search for the second title
5. Preview and loading the second title
6. Steady state playtime for the second title (1 min)

Takeaways:

- Netflix contains multiple interactive and non-interactive steps
- 10 Mbps download throughput results in a VMOS of 5 for user quality of experience (QoE)
- For a VMOS of 4, the download throughput cannot be less than 3 Mbps

Netflix Script Demo

HughesScripts › main.py

main.py | main_spotify.py | Credentials.py

```python
time.sleep(4)
# searchButton = driver.find_element_by_xpath('/html/body/div[1]/div/div/div[1]/div[1]/div[1]/div[1]/div/div[1]/div/div[1]/div/button').click()
# time.sleep(4)
search_box = driver.find_element_by_class_name('searchTab')
search_box.click()
search_box = driver.find_element_by_css_selector("input[placeholder='Titles, people, genres']")
search_box.send_keys('Don\'t Look Up')
time.sleep(4)
viewButton = driver.find_element_by_xpath('/html/body/div[1]/div/div/div[1]/div[1]/div[2]/div/div/div[2]/div[2]/div/div/div[1]/div/div/div/div/div/div[1]/div/div/div[1]/a').click()
time.sleep(2)
# playButton = driver.find_element_by_xpath('/html/body/div[2]/div/div/div[1]/div[2]/div/div[1]/div[4]/div/div[1]/div[1]/a/button').click()
playButton = driver.find_element_by_xpath('/html/body/div[2]/div/div/div[1]/div[2]/div/div[1]/div[4]/div/div[1]/div[2]/a/button').click()

time.sleep(10)
driver.get('https://netflix.com')
time.sleep(4)
search_box = driver.find_element_by_class_name('searchTab')
search_box.click()
search_box = driver.find_element_by_css_selector("input[placeholder='Titles, people, genres']")
search_box.send_keys('Apostle')
time.sleep(4)
viewButton = driver.find_element_by_xpath('/html/body/div[1]/div/div/div[1]/div[1]/div[2]/div/div/div[2]/div[2]/div/div/div[1]/div/div/div/div/div/div[1]/div/div/div[1]/a').click()
time.sleep(2)
playButton = driver.find_element_by_xpath('/html/body/div[2]/div/div/div[1]/div[2]/div/div[1]/div[4]/div/div[1]/div[1]/a/button').click()
time.sleep(10)
driver.quit()

# profileButton = driver.find_element_by_xpath('/html/body/div[1]/div/div/div[1]/div[1]/div[2]/div/ul/li[1]').click()
# profileButton = driver.find_element_by_xpath('/html/body/div[1]/div/div/div[1]/div[1]/div[2]/div/ul/li[1]/div/a').click()

# mylistButton = driver.find_element_by_xpath('/html/body/div[1]/div/div/div[1]/div[1]/div[1]/div/div/ul/li[6]/a').click()
# playButton = driver.find_element_by_xpath('/html/body/div[2]/div/div/div[1]/div[1]/div[2]/div/div[2]/div/div/div[1]/div/div/div/div/div/div[3]/div/div/div[1]/a').click()
```

Run: main

```
    playButton = driver.find_element_by_xpath('/html/body/div[2]/div/div/div[1]/div[2]/div/div[1]/div[4]/div/div[1]/div[2]/a/button').click()
  File "/Users/nariman/opt/anaconda3/envs/HughesScripts/lib/python3.8/site-packages/selenium/webdriver/remote/webdriver.py", line 394, in find_element_by_xpath
    return self.find_element(by=By.XPATH, value=xpath)
  File "/Users/nariman/opt/anaconda3/envs/HughesScripts/lib/python3.8/site-packages/selenium/webdriver/remote/webdriver.py", line 976, in find_element
    return self.execute(Command.FIND_ELEMENT, {
  File "/Users/nariman/opt/anaconda3/envs/HughesScripts/lib/python3.8/site-packages/selenium/webdriver/remote/webdriver.py", line 321, in execute
    self.error_handler.check_response(response)
  File "/Users/nariman/opt/anaconda3/envs/HughesScripts/lib/python3.8/site-packages/selenium/webdriver/remote/errorhandler.py", line 242, in check_response
    raise exception_class(message, screen, stacktrace)
selenium.common.exceptions.NoSuchElementException: Message: no such element: Unable to locate element: {"method":"xpath","selector":"/html/body/div[2]/div/div/div[1]/div[2]/div/div[1]/div[4]/div/div[1]/div[2]/a
  (Session info: chrome=99.0.4844.84)


Process finished with exit code 1
```

Run | TODO | Problems | Terminal | Python Console | Event Log

50:14 LF UTF-8 4 spaces Python 3.8 (HughesScripts)

Netflix Non-/Interactive Step Classification (INFRA)

Step	Peak Downlink Throughput (Mbps)	Peak Uplink Throughput (Mbps)	Class
Login and 1st Title Search	7.52	0.48	Interactive
1st Load and Preview	12.00	0.32	Interactive
1st Steady State Playtime	16.48	0.24	Bulk
Main Menu and 2nd Title Search	9.04	0.56	Interactive
2nd Load and Preview	9.6	0.32	Interactive
2nd Steady State Playtime	11.44	0.24	Bulk

Netflix Non-/Interactive Step Classification (HTSP)

Step	Peak Downlink Throughput (Mbps)	Peak Uplink Throughput (Mbps)	Class
Login and 1st Title Search	6.16	0.32	Interactive
1st Load and Preview	3.84	0.16	Interactive
1st Steady State Playtime	13.04	0.24	Bulk
Main Menu and 2nd Title Search	6.24	0.24	Interactive
2nd Load and Preview	4.64	0.16	Interactive
2nd Steady State Playtime	9.6	0.24	Bulk

Web browsing (Chrome)

- Goals
  - Classifying web browsing traffic to bulk and interactive
  - Finding the minimum LTE capacity for acceptable delivery of browsing interactive traffic
- Websites: popular websites in the US
  google.com, amazon.com, wikipedia.org, twitter.com
- Takeaways:
  - The google.com DL/UL interactive peak rates are 8/1
  - A capacity of 3/2 Mbps (layer 2) for Interactive traffic results in the highest QoE

Domain	Visits
google.com	17.98B
youtube.com	4.26B
facebook.com	3.89B
amazon.com	3.30B
wikipedia.org	3.10B
yahoo.com	1.83B
reddit.com	1.28B
instagram.com	939.19M
twitter.com	932.14M
ebay.com	884.89M
fandom.com	741.28M

https://www.semrush.com/blog/most-visited-websites/
https://statisticsanddata.org/data/most-popular-websites-in-the-world-1996-2021/

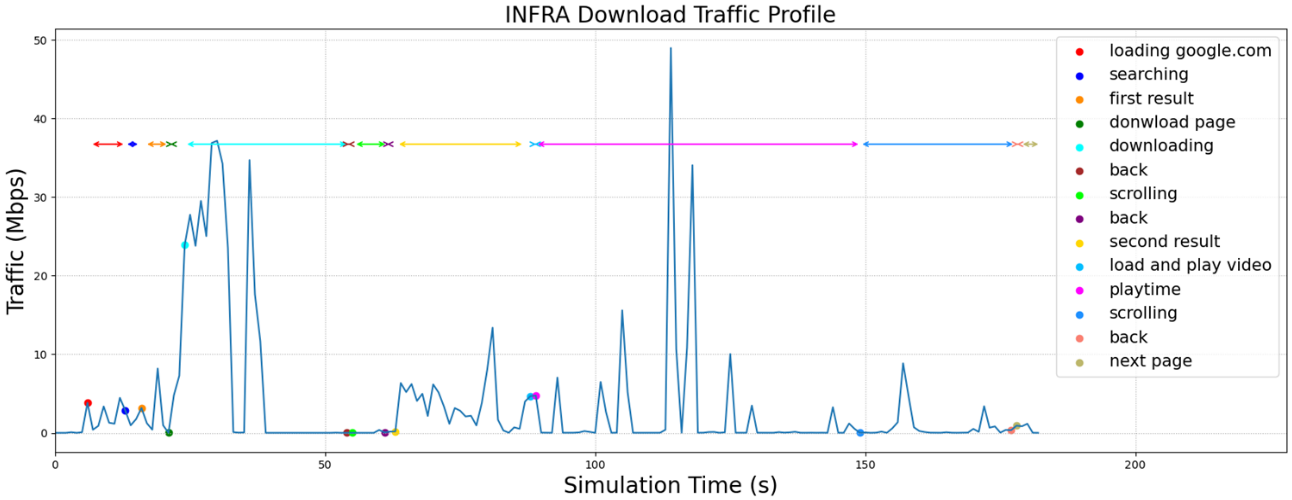
google.com

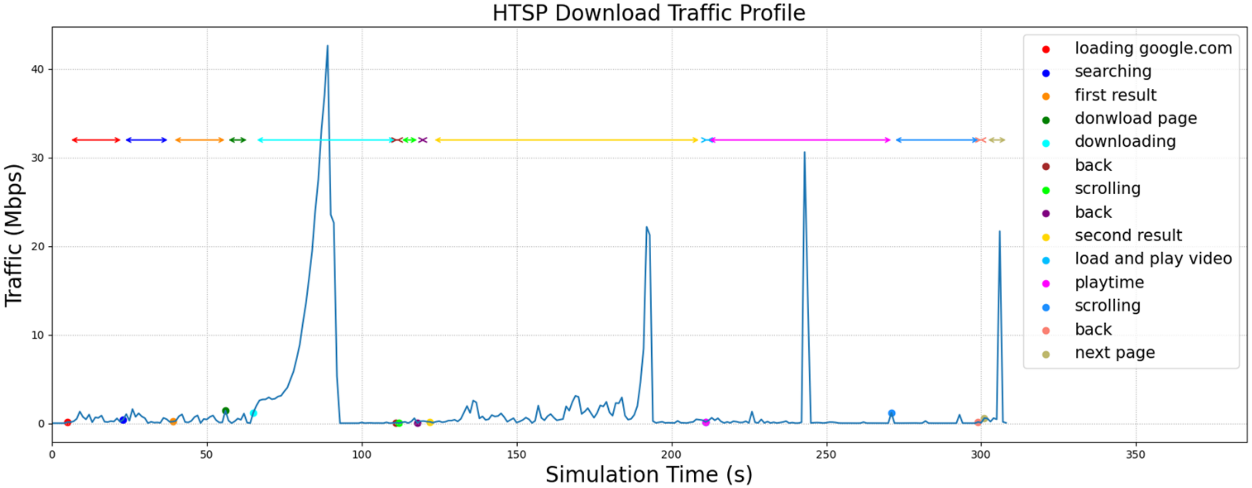
- Steps

  1. Search a word/sentence

  2. Check the first two results, at each:
     - Load
     - Scroll and pause (2 sec)
     - Download a file (40MB) – in result (website) 1
     - Play a video (1 min) – in result (website) 2

  3. Next page





Gaming Analysis – Benchmark CoD

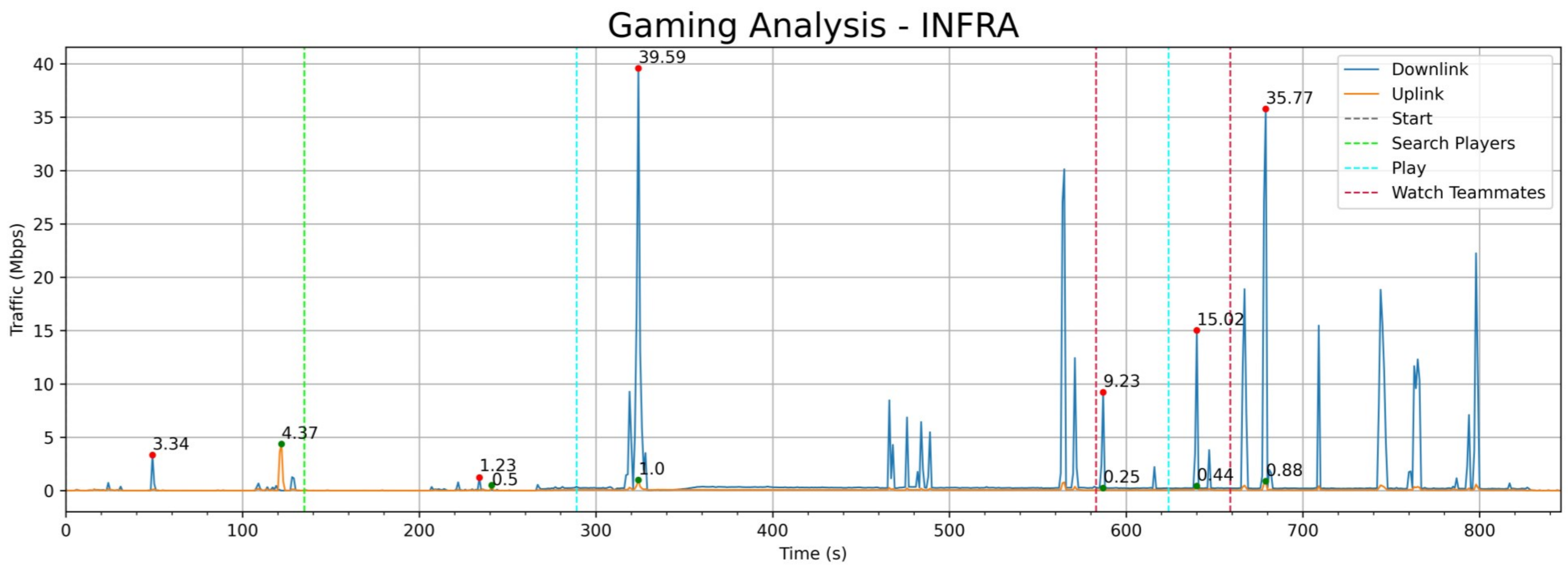
I: Interactive
n/I: not Interactive

1. Start the game (loading until click prompt) – (n/I)
2. Checking for updates – (n/I)
3. Game selection (stage, etc.)
   a. Selection core – (n/I)
   b. Finding players - searching for a match, needs ping <150ms, compromise up to <200ms – (I)
4. Playing the game
   a. While alive – (I)
   b. Player eliminated, teammates keep playing, player can switch video perspective – (n/I)
5. Loop 4.
6. Ending the game and exiting (n/I)

unified (items 1–3a)

Section Identification DNS packet:

- 11:22:00.717861
- 8.8.8.8
- 10.11.4.150
- DNS
- 192
- Standard query response 0xdf78 A gs-sec.ww.np.dl.playstation.net CNAME wild.ww.np.dl.playstation.net.edgekey.net CNAME e1800.d.akamaiedge.net A 173.223.176.157



Start	Search Players	Play	Watch Teammates	Play	Watch Teammates
0	135s	289s	583s	624s	659s

MOS	1st OS	2nd OS
3.25	3.5	3

Pleak DL Rate	Peak UL Rate
39.59 Mbps	4.37 Mbps

Video Conferencing Applications: Roundtrip Delay

- Experimental Design

1. Speaker A says “Over”
2. Speaker A immediately starts a stopwatch
3. Speaker B says “Received” immediately once they hear “Over”
4. Speaker A stops the stopwatch immediately once they hear “Received”
5. Speaker A records the measurement of the stopwatch

Zoom

- INFRA: 0.72s (human reaction time, not noticeable)
- HTSP: 1.33s (slightly noticeable)

MS Teams

- INFRA: 0.73s (human reaction time, not noticeable)
- HTSP: 1.39s (slightly noticeable)

Video Conferencing Meeting: Steps

- One-on-one Meetings Steps

➢ Steps of the test user (host always has video on)

1. Joining by clicking an invitation link
2. Conversation with video off
3. Conversation with video on
4. Conversation with video on and screen sharing

- Group Meeting Steps

1. Test user joins by clicking an invitation link
2. One-on-one meeting with video on
3. Third participant joins with video on

...

6. Sixth participant joins with video on
7. Test user turns screen-sharing on

One-on-one Meeting – Zoom

- INFRA QoE

Speaker 1: 5/5

Speaker 2: 5/5

- HTSP QoE

Speaker 1: 4/5

Speaker 2: 4/5

- MOS
  - INFRA: 5/5 (excellent session)
  - HTSP: 4/5 (slightly noticeable delay and very few audio drops)

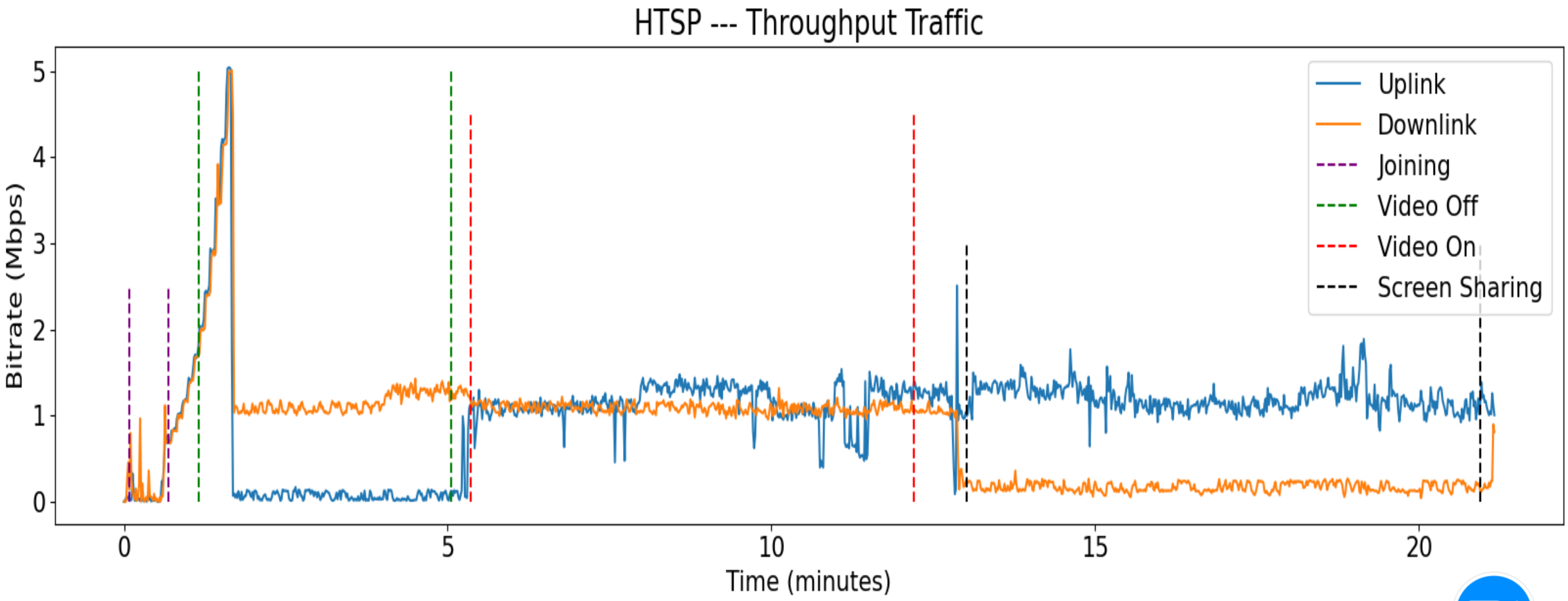
Key Takeaways

- MOS of HTSP: 4/5
- One-on-one meetings can be routed through HTSP
- The duration of "Joining" step is 3 times larger when using HTSP (not very noticeable)
- The peak bitrate is 5 Mbps at the start of the meeting
- The bitrate is around 1-2 Mbps when video is on, less than 1 Mbps when video is off
- Participants may be sending video with lower resolution during screen-sharing

Conclusion: Zoom one-on-one meetings can be routed through the HTSP link

➢ ***Similar conclusions were reached for MS Teams***

One-on-one Meeting – Zoom



Group Meeting – Zoom

- INFRA QoE Scores

All Participants: 5/5

- HTSP QoE Scores

Four Participants + 1 observer: [4/5, 4/5, 5/5, 3.5/5, 3/5]

- MOS
  - INFRA: 5/5 (excellent session)
  - HTSP: 3.9/5 (slightly noticeable delay and very few audio drops)

Key Takeaways

- MOS of HTSP: 3.9/5
- Group meetings can be routed through HTSP
- A peak of 5 Mbps appears every time a participant joins
- The steady state downlink bitrate increases by 0.5-1 Mbps every time a new participant joins
- The steady state uplink bitrate remains the same

Conclusion: Zoom group meetings can be routed through the HTSP link

➢ ***Similar conclusions were reached for MS Teams***

Conclusions

- We found that several widely used applications can be served equally well (as measured by the MOS) by either hybrid or terrestrial networks
- We also found others that they cannot
- Highly interactive gaming was analyzed yielding medium QoE for 100ms delay, while analysis of less interactive ones is in progress

	Terrestrial	**Satellite**	**Hybrid**
Video Streaming	*Yes*	*Yes*	*Yes*†
Web Browsing	*Yes*	*Yes*	*Yes*†
Video Conferencing	*Yes*	*Yes*	*Yes*†

†*Hybrid yields comparable QoE with that of Terrestrial network, for interactive steps*

Future Directions

- Set-up at the UMD a real-life experimental setup (real wireless 5G and satellite devices/networks)
- Scale up the experiments in terms of both number of users and applications
- Statistically analyze the data for more accurate utilization in dynamic resource allocation
- Write reports and papers (public)
- Make the data and measurements publicly available

Thank you!

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Questions?