Analysing the Performance of Cloud Gaming over a Low-Earth Orbit Satellite Network

Link to the Full Report

University of Victoria

Introduction

- Space-Air-Ground Integrated Networks (SAGINs) are going to be a game changer for providing a more flexible and larger scale network coverage [1].
- Starlink, a SpaceX division, is one of these game changers that provides a global internet coverage through a constellation of Low-Earth Orbit (LEO) satellites [2]. These satellites help establish a connection between ground stations and user dishes.
- While the LEO satellites enable a wider coverage, due to their high mobility, the satellite-to-ground transmissions suffer from handovers that are needed to maintain a connection [3].
- For Starlink, to make the scheduling easier, these satellite handovers occur every 15 seconds and they are synchronised globally at 57, 12, 27, and 42 seconds after each minute [4].
- The fast-changing latency caused by these handovers degrades the performance of multimedia services, especially two-way interactive applications [5].
- Cloud gaming works by rendering the game on a remote server to be streamed to the player and receiving inputs from a local system over the internet [6]. The challenge is that the latency of the remote server makes the user even more sensitive to the latency changes in the network. This makes cloud gaming especially challenging over a LEO satellite network.
- So, combining cloud gaming with Starlink creates the opportunity for playing PC games from anywhere without the expensive hardware. However, one question remains: How does the latency changes caused by satellite handovers affect the cloud gaming performance?

Methods

- Rocker League, a vehicular soccer video game, on Geforce Now (GFN), a cloud gaming service, was used as the testing scenario. The stream resolution was fixed to 1080p at 60 frames per second (FPS) and the server location was fixed in respect to each system's location for fair testing.
- A selenium python script was used to make two systems each join their own independent private match and collect data simultaneously and automatically for 2 minutes per round [7].
    - Metrics such as ping, total round packet loss, used bandwidth, available bandwidth, stream resolution [1], and stream FPS [1] were collected from the GFN networks stats overlay.
    - Input latency was approximated using screenshots by boosting the car forward and measuring the time between the input and action [2] (Figure 1).

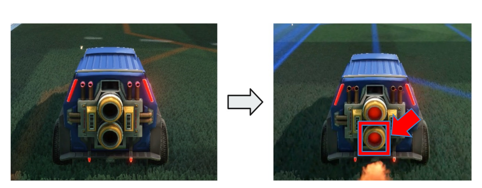

Figure 1. Input vs. Action Frame

- The systems used in this study were all the same low-mid tier Ubuntu min-PC. These systems were set up in three different locations where Starlink was also set up: Victoria, Vancouver, and Ottawa.
- The systems were connected to either a Telus Fibre network (Figure 1) or Starlink network (Figure 2) via Gigabit ethernet unless specified otherwise.
- The network scenarios considered (Table 1) were chosen to capture baseline measurements within a traditional network, measurements comparing Starlink and a traditional network, and measurements comparing Starlink in different locations with varying commonalities.
- For each scenario, 48 rounds of data (2 minutes/round) were collected throughout a day consisting of 12 rounds at: 9:00 a.m (morning), 1:00 p.m (afternoon), 5:00 p.m (evening), and 9 p.m (night). The times were all in PDT, except for "Victoria Starlink vs. Ottawa Starlink" which used EDT. Also, the tests were only run Monday to Thursday to avoid peak days, given that there was not enough time to consider peak days for each of the scenarios.

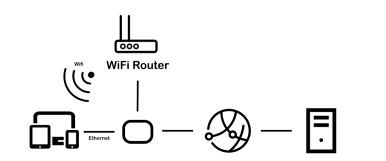

Figure 2. Telus Fibre Network Topology

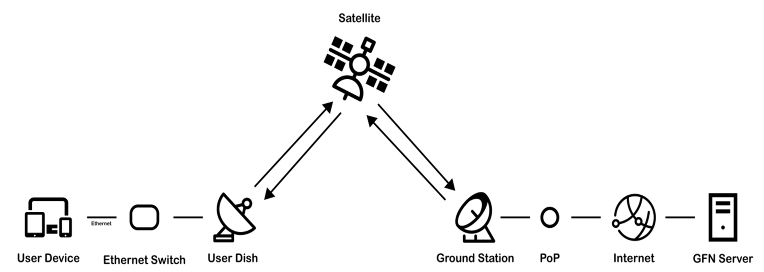

Figure 3. Starlink Network Topology

Results

		Ping (ms) (mean / SD)	Input Latency (ms) (mean / SD)	Round Packet Loss (mean / SD)	Round Packet Loss (%) [3] (mean / SD)	Available Bandwidth (Mbps) (mean / SD)	Used Bandwidth (Mbps) (mean / SD)
Victoria Telus vs. Victoria Telus (Same Household)	Victoria Telus Fibre 1	31.42 / 1.53	72.89 / 25.50	62.27 / 177.72	0.025% / 0.071%	82.33 / 12.78	19.18 / 1.73
	Victoria Telus Fibre 2	31.21 / 1.52	74.61 / 28.61	62.10 / 185.86	0.025% / 0.074%	81.86 / 12.54	19.34 / 1.69
Victoria Starlink vs. Victoria Telus	Victoria Starlink	67.04 / 26.50	116.92 / 84.68	460.04 / 435.34	0.184% / 0.174%	56.87 / 18.5	15.89 / 4.91
	Victoria Telus Fibre	31.41 / 1.61	74.64 / 25.15	16.88 / 48.42	0.007% / 0.019%	82.80 / 12.85	19.22 / 1.61
Victoria Starlink vs. Victoria Starlink	Victoria Starlink 1	70.26 / 27.93	121.68 / 87.10	730.75 / 641.52	0.292% / 0.257%	46.75 / 14.20	15.17 / 4.88
	Victoria Starlink 2	70.41 / 29.05	121.56 / 97.66	862.04 / 925.39	0.345% / 0.370%	46.54 / 14.12	15.19 / 4.97
Victoria Starlink vs. Vancouver Starlink	Victoria Starlink	67.44 / 28.09	116.95 / 76.52	608.60 / 401.52	0.243% / 0.161%	57.30 / 17.40	16.02 / 4.98
	Vancouver Starlink	65.88 / 20.68	118.32 / 91.47	727.04 / 419.68	0.291% / 0.168%	61.60 / 21.58	16.29 / 4.91
Victoria Starlink vs. Ottawa Starlink	Victoria Starlink	65.29 / 21.27	117.24 / 82.65	745.54 / 590.57	0.298% / 0.236%	59.78 / 16.09	17.43 / 4.11
	Ottawa Starlink	60.57 / 21.35	106.84 / 82.22	597.60 / 296.46	0.239% / 0.119%	51.49 / 24.37	13.85 / 5.06

Table 1. Mean and Standard Deviation of Network Metrics

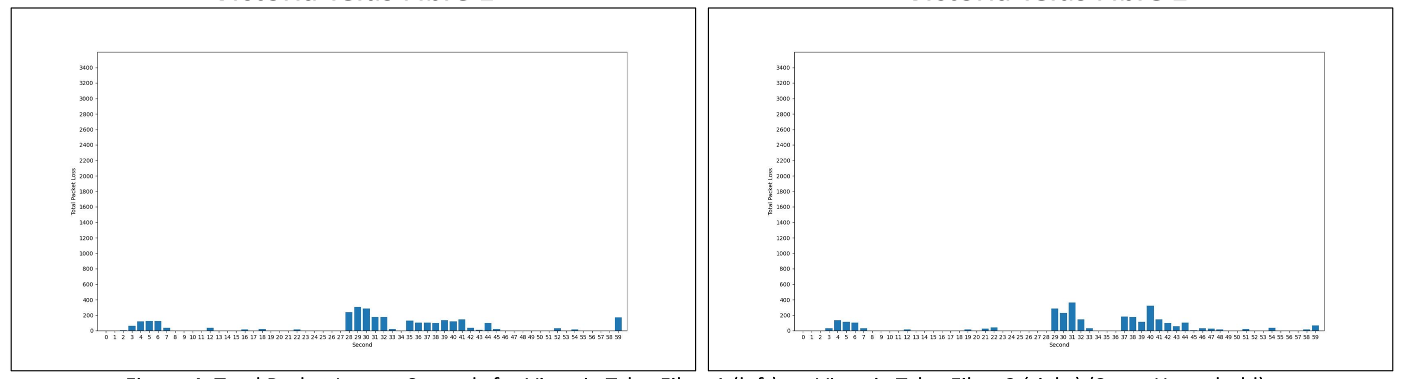

Figure 4. Total Packet Loss at Seconds for Victoria Telus Fibre 1 (left) vs. Victoria Telus Fibre 2 (right) (Same Household)

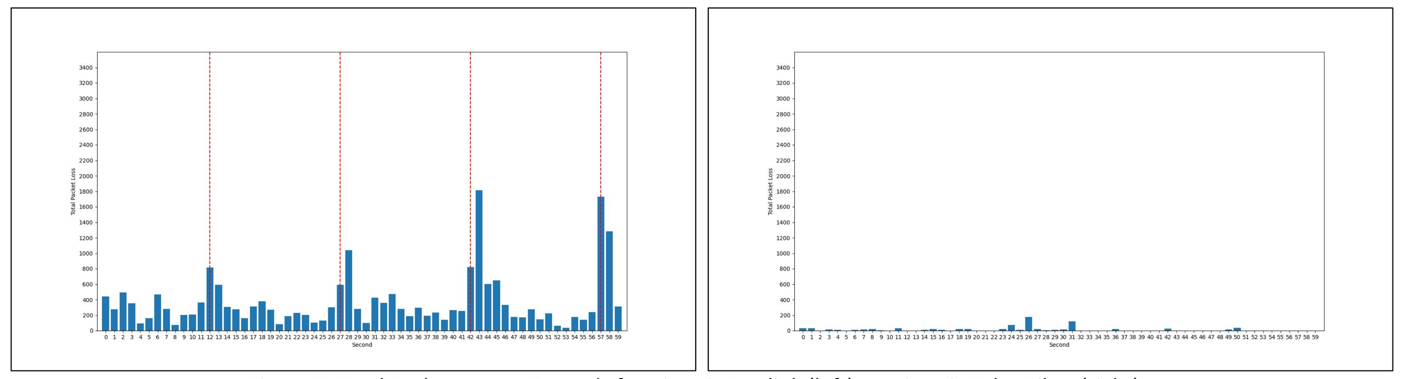

Figure 5. Total Packet Loss at Seconds for Victoria Starlink (left) vs. Victoria Telus Fibre (right)

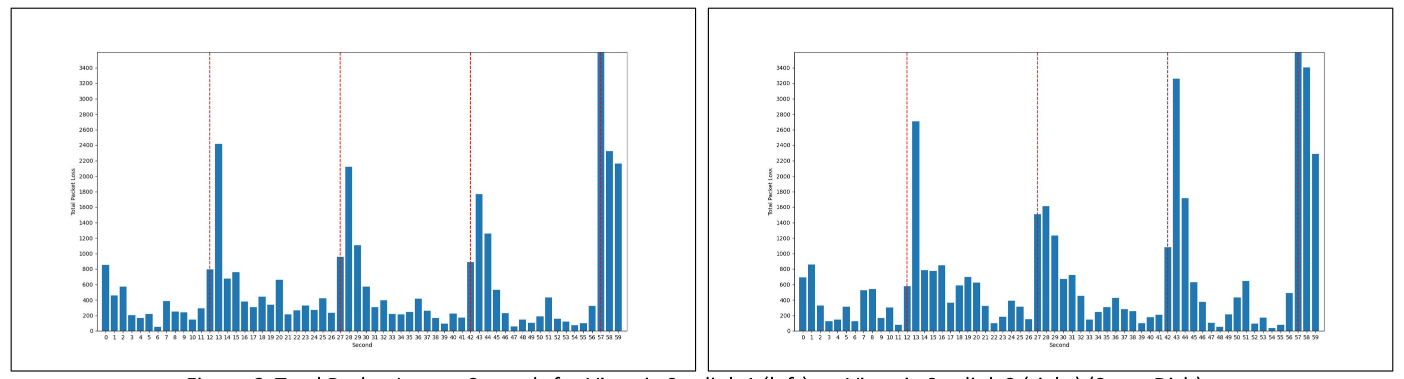

Figure 6. Total Packet Loss at Seconds for Victoria Starlink 1 (left) vs. Victoria Starlink 2 (right) (Same Dish)

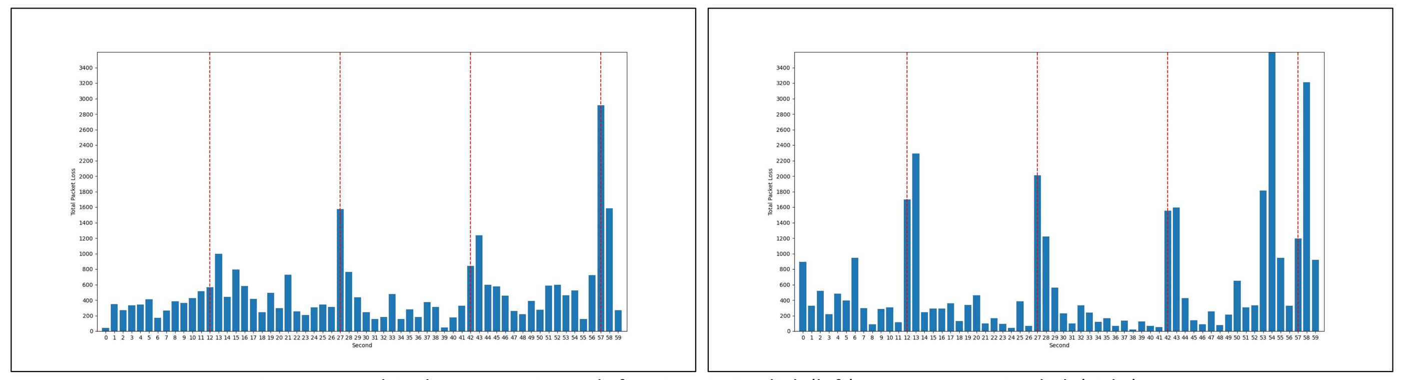

Figure 7. Total Packet Loss at Seconds for Victoria Starlink (left) vs. Vancouver Starlink (right)

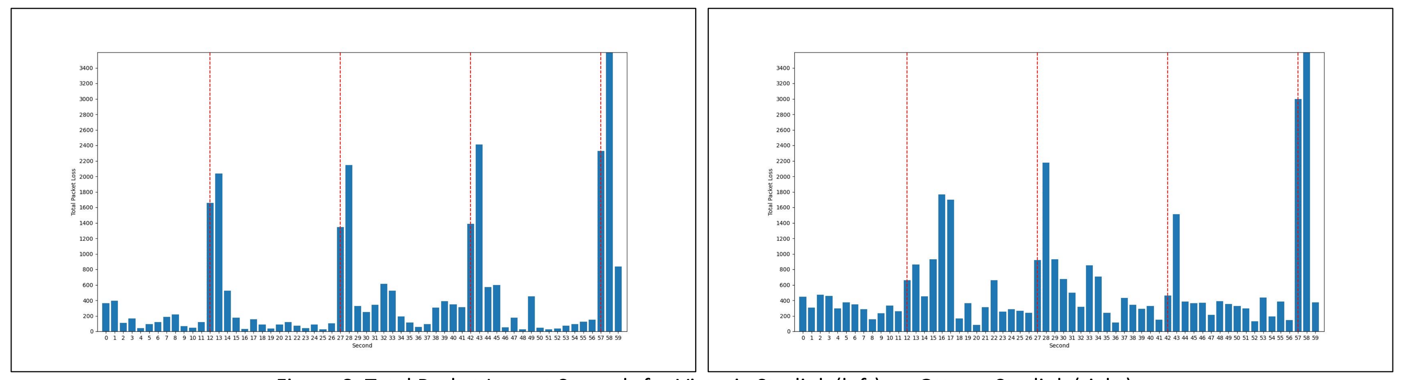

Figure 8. Total Packet Loss at Seconds for Victoria Starlink (left) vs. Ottawa Starlink (right)

Discussion

- Based on the results in Table 1, the biggest difference in the network performance was between Victoria Starlink and Victoria Telus Fibre. Compared to Victoria Telus Fibre, Victoria Starlink had
    - A considerably higher average for ping (2.3x), input latency (1.6x), and packet loss (9.0x). While the available bandwidth for Victoria Starlink was noticably lower (1.5x), the used bandwidth was not that much different (1.2x).
    - A much higher standard deviation for ping (16.4x), input latency (3.4x), packet loss (9.0x), available bandwidth (1.4x), and used bandwidth (3.0x).
- An interesting pattern was revealed when packet loss was organized by seconds in a minute. As it can be seen in Figures 4-8, the noticeable peaks for total packet loss only appeared on the Starlink networks.
- These peaks occurred around the same time that the satellite handovers took place (marked by red dotted lines), and the effect of these handovers lasted several seconds despite the actual handovers only taking about 100 milliseconds.
- Another interesting observation is that the handovers at the 57 second mark seem to have caused the highest peaks most of the time, but the reason for this is not clear yet.

Conclusion

- In short, this measurement study revealed that compared to a more traditional network, the Starlink network has higher and faster changing latency, less stable bandwidth, and more packet loss consistently across the different locations (Victoria, Vancouver, and Ottawa).
- While the performance difference of the Starlink network was in part due to communication with distant satellites, there were also frequent and predictable performance drops caused by satellite handovers.
- Starlink's fixed and synchronised approach to satellite handover is effective for maintaining connection, but as the results reveal, it is not efficient. However, since it is predictable, it can be taken advantage of by services such as GFN.
    - An application layer codec design can be used to smooth out packet loss introduced by the handovers.
    - Application and transport layer can schedule the data transfer to avoid handover events.
- So, although this study does not directly tackle the performance issues of cloud gaming over Starlink, it helps to shed some light on what needs to be addressed in future works.

References

[1] J. Liu, Y. Shi, Z. M. Fadlullah, and N. Kato, "Space-Air-Ground Integrated Network: A Survey," *IEEE Communications surveys and tutorials*, vol. 20, no. 4, pp. 2714–2741, 2018, doi: 10.1109/COMST.2018.2841996. [Accessed Aug. 21, 2023]

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1. The results and discussion for the stream quality metrics and the "Victoria Telus Fibre vs. Victoria Telus Fibre via Wifi (different household)" scenario are not included in this poster, but they can be found in the report.
2. Each screenshot had an average latency of around 53 ms, so this method might not be able to capture input latencies in the lower range.
3. Packet loss ratio was approximated using a fixed total number of packets that was decided based on observations: 250,000 packets.

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