LENS: A LEO Satellite Network Measurement Dataset

Jinwei Zhao
University of Victoria
Victoria, BC, Canada
clarkzjw@uvic.ca

Jianping Pan
University of Victoria
Victoria, BC, Canada
pan@uvic.ca

ABSTRACT

Low-Earth-Orbit (LEO) satellite constellations are narrowing the performance gap between satellite networks and the terrestrial Internet. Low-latency satellite Internet offered by Starlink enables functionalities that are otherwise unachievable with the traditional geosynchronous equatorial orbit (GEO) satellite networks, including low-latency live video streaming, cloud gaming and real-time video conferencing. The absence of a comprehensive and long-term network measurement dataset with a global perspective poses significant challenges for researchers to evaluate the application performance over Starlink networks. In this paper, we introduce LENS, which is a LEO satellite network measurement dataset, collected from 13 Starlink dishes, associated with 7 Point-of-Presence (PoP) locations across 3 continents. The dataset currently consists of network latency traces from Starlink dishes with different hardware revisions, various service subscriptions and distinct sky obstruction ratios. We provide a high-level overview and analysis of the latency performance using the dataset and discuss various use cases. This dataset is useful for researchers who wish to understand the long-term network performance of Starlink and to evaluate and optimize the performance of multimedia applications over satellite networks.

CCS CONCEPTS

• **Networks → Network measurement**.

KEYWORDS

LEO, Latency, Network Measurement, Inter-Satellite Links, Dataset

ACM Reference Format:
Jinwei Zhao and Jianping Pan. 2024. LENS: A LEO Satellite Network Measurement Dataset. In *ACM Multimedia Systems Conference 2024 (MMSys '24), April 15–18, 2024, Bari, Italy*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3625468.3652170

1 INTRODUCTION

Low-Earth-Orbit (LEO) satellite networks have seen a resurgence in recent years, with the reduced launch costs enabled by reusable rockets and the increased demand for Internet connectivity with 5G and beyond. The widespread deployment of LEO satellite mega-constellations such as Starlink enables global Internet coverage, with more than two million subscribers in over 60 countries as of 2023. Traditional satellite Internet service providers (ISPs) utilize satellites deployed in geosynchronous equatorial orbits (GEO) or medium-Earth-orbits (MEO), which eventually leads to higher latency due to the longer transmission distance. LEO satellite networks facilitate low-latency Internet access with global coverage, particularly benefiting remote and rural communities that would otherwise remain disconnected or rely solely on high-latency GEO satellite networks.

Laser inter-satellite link (ISL) plays a fundamental role in the Starlink constellation to achieve low-latency Internet connectivity with global coverage. However, the inter-satellite routing schemes are transparent to the IP layer, making it difficult to demystify the usage of ISLs in Starlink networks from the perspective of networking measurements, without further disclosure of the technical details from Starlink. Nevertheless, with more intelligent and advanced ISL routing algorithms being deployed, Starlink's ISL will eventually be essential to reduce the latency of long-haul connections over Starlink networks because of the faster speed of light in space than in fiber optics.

Since SpaceX launched Starlink beta testing in 2020, it has attracted abundant research interest. Zhao et al. [16] demonstrated that with properly configured buffers, most multimedia systems including video-on-demand (VoD) and live video streaming show similar performance over Starlink as over terrestrial networks. By utilizing trace-driven simulations and emulations, researchers can optimize the performance of transport layer protocols and applications over satellite networks [3, 14]. However, the research community lacks a comprehensive and long-term dataset of Starlink's network performance, particularly one that offers global insights from dishes associated with different Point-of-Presence (PoP) locations and provides ground truth measurements of ISL performance.

In this paper, we present LENS, which is a LEO satellite network measurement dataset collected from 13 Starlink dishes worldwide, associated with 7 PoPs across 3 continents, including Africa, North America, and Europe. These dishes have different hardware revisions and service tiers. They are located at geographical locations with various sky obstruction ratios and latitudes, providing a diverse set of alignment conditions. LENS also contains the first long-term assessment of Starlink's ISL performance with a dish located in the Western Indian Ocean, along with the initial investigation of Starlink's inaugural 10 Gbps community gateway in Alaska.

We publicly release our dataset on GitHub[1] to the research community, which can be used in trace-driven simulations and emulations to optimize the performance of multimedia applications over Starlink networks. The main contributions of this paper are summarized as follows:

[1]https://github.com/clarkzjw/LENS

MMSys '24, April 15–18, 2024, Bari, Italy

ACM ISBN 979-8-4007-0412-3/24/04…$15.00
https://doi.org/10.1145/3625468.3652170

- We conducted a comprehensive and long-term network measurement of Starlink, with a specific focus on the latency performance of Starlink access networks.
- We presented a network measurement dataset that can be utilized in trace-driven simulations and emulations to optimize the performance of multimedia applications over Starlink networks.
- We provided a high-level overview and analysis of the dataset, offering insights into the latency performance of Starlink networks from various aspects.

The rest of the paper is organized as follows. Section 2 introduces existing measurement efforts on Starlink networks. Section 3 presents our measurement methodologies and the data acquisition pipeline. Section 4 describes our analysis of the dataset. Section 5 discusses potential use cases of our dataset. Section 6 concludes the paper.

2 RELATED WORK

In this section, we focus on existing network measurements that were conducted over Starlink networks.

Hu et al. [5] compared the coverage of Starlink deployment with major cellular carriers in the United States, and investigated the potential benefits of multipath transport protocols utilizing both LEO satellite and cellular networks. They also explored the mobility of Starlink dishes by driving through five states in the United States, considering different geographical areas, infrastructure deployment densities and user populations.

Liz et al. [7] proposed *HitchHiking*, building on the observation that Internet-exposed services with LEO satellite operators can reveal a glimpse of the network architecture and performance. They conducted a large-scale study of Starlink network latency, measuring over 2,400 users across 27 countries by *outside-in* probing measurements. Notably, they captured one Starlink customer who is supposedly on a yacht near Seychelles, by examining the TLS certificate associated with the public IP address of the user. Since the yacht near Seychelles is thousands of kilometers away from the only Starlink African PoP in Nigeria and has no access to any ground stations within a 5,000 km radius, the customer must solely rely on Starlink's ISL to remain connected to the Internet. The authors also assumed the user is likely to be re-routed to further ground stations frequently, as the user's round-trip time (RTT) is 150 ms over its minimum RTT during 42% of the measurement period. They concluded that at least 70% of Starlink customers experience at least one sustained latency spike every day, and they are not always caused by satellite changes.

Due to the barrier of having no direct access to different Starlink dishes worldwide, researchers have been utilizing public datasets from M-Lab and RIPE Atlas to study the performance of Starlink networks. The M-Lab Network Diagnostic Tool (NDT) dataset[2] was collected from user-initiated speed tests, lacking long-term continuity in the measurement. It does not contain a ground truth to verify the geolocation and ASN mapping of client IP addresses, thus introducing potential biases in the analysis. As of January 2024, there are 84 RIPE Atlas probes deployed in Starlink networks that remain active (27 Disconnected and 16 Abandoned) [2]. Most of them are located in North America and Europe, with only a few deployed in other continents. The RIPE Atlas network especially lacks probes utilizing Starlink's ISLs, except one located in the Réunion Island which is supposedly utilizing ISLs. RIPE Atlas probes only have limited measurement intensity and granularity. For example, the minimal interval between ping packets is 1 second, which is not sufficient to capture the 15-second handover behavior of Starlink networks [13].

[2]https://www.measurementlab.net/tests/ndt/

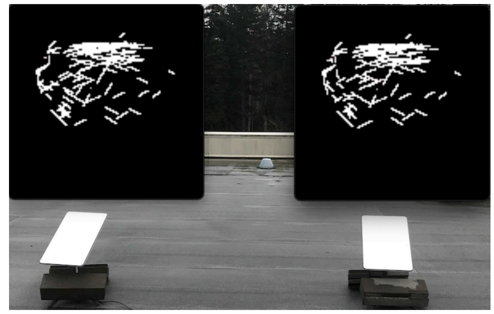


Figure 1: Side-by-side dishes when building the obstruction map

Aravindh et al. [12] utilized both datasets to characterize the low-level performance and footprint of 18 different satellite network operators with a specific focus on Starlink. They evaluated 67 RIPE Atlas probes in 15 countries between May 2022 and May 2023 and investigated the latency from the probes to their respective Starlink PoPs and root DNS servers. They did not observe statistically significant variations of RTT to the PoPs over one year for most probes, except one probe in New Zealand changed its PoP from Sydney to Auckland in June 2022. However, among the 67 probes in 15 countries, they were all supposedly utilizing the "bent-pipe" architecture, thus lacking the performance evaluation of ISLs.

Nitinder et al. [10] also utilized M-Lab speed test datasets from 34 countries since 2021 and over 98 RIPE Atlas probes in 21 countries to analyze Starlink's performance relative to terrestrial cellular networks and evaluated the last-mile access networks and other factors affecting Starlink's performance globally. They conducted controlled *inside-out* experiments from Starlink dishes in two European countries to analyze the impact of the globally synchronized 15-second handover behavior.

3 DATA ACQUISITION

In this section, we introduce the methodologies, hardware specifications and environmental settings for our network measurements and the data acquisition pipeline.

3.1 Methodology

For regular Starlink subscribers, carrier-grade NAT (CGNAT) is utilized by Starlink to allocate IPv4 addresses. An IPv4 address is allocated and bound to the associated gateway of their home PoPs [11]. User dishes can always reach the gateway at `100.64.0.1` in one IP hop. Starlink subscribers with the *Priority* plan receive a public IPv4 address bound to their Starlink user routers, which is reachable from the Internet. Starlink networks also support native

Table 1: Starlink dishes and locations for *inside-out* measurements

Dish ID	Location	Hardware Version	Sky Obstruction Ratio (%)	Time Obstruction Ratio (%)	PoP	Service Tier
victoria_active_1	Victoria, BC, CA	*rev3_proto2*	0.264	0.002	Seattle	Standard
victoria_active_2	Victoria, BC, CA	*rev3_proto2*	0	0	Seattle	Mobile
victoria_inactive	Victoria, BC, CA	*rev3_proto2*	0	0	Seattle	Inactive Mobile, Roam
vancouver	Vancouver, BC, CA	*rev2_proto3*	4.564	0.097	Seattle	Standard
seattle	Seattle, WA, USA	*rev3_proto2*	10.198	0.801	Seattle	Standard
seattle_hp	Seattle, WA, USA	*hp1_proto1*	0.257	0.059	Seattle	Priority
ottawa	Ottawa, ON, CA	*rev3_proto2*	13.961	0.449	New York	Standard
iowa	Iowa City, IA, USA	*rev1_pre_production*	0.516	0	Chicago	Standard
denver	Denver, CO, USA	*rev3_proto2*	0.071	0.027	Denver	Mobile, Roam
louvain	Louvain, Belgium	*rev3_proto2*	0.027	0	Frankfurt	Standard
seychelles	Seychelles	*rev3_proto2*	0.646	0.022	Lagos / Frankfurt	Mobile, Roam
alaska	Anchorage, AK, USA	*rev3_proto2*	0.029	0.006	Seattle	Mobile
dallas	Oxford, MS, USA	*rev3_proto2*	15.979	3.914	Dallas	Inactive Standard

IPv6, with a /64 IPv6 prefix allocated to the user router. Starlink subscribers can get end-to-end IPv6 connectivity with proper configurations using third-party routers since the stock Starlink user router currently does not accept incoming IPv6 traffic and lacks configuration capabilities.

In this dataset, we utilized both *inside-out* and *outside-in* measurement methodologies. *Inside-out* measurements are conducted on Starlink dishes to which we have direct access, either locally or remotely through collaboration with other Starlink users and researchers. In this scenario, we deploy physical hardware or a virtual machine in the Starlink network to conduct active network measurements. For *inside-out* measurements, we mainly focus on the Starlink access network latency between user dishes to the associated gateway of their home PoPs. We measured the RTT from a user dish to the gateway at `100.64.0.1` using ICMP-based `ping`. With cloud servers deployed at data centers closely interconnected with Starlink's backbone infrastructure, we also conducted UDP-based end-to-end latency measurements with `IRTT`[3].

Starlink user dishes remain valuable tools for conducting latency measurements even without active subscriptions. Users retain access to certain Internet addresses on inactive dishes, for instance, *connect.starlink.com*, enabling them to reactivate subscriptions. We can measure the access network latency using inactive dishes by sending ICMP echo requests to a reachable IP address but setting TTL=1 to only reach the gateway. The gateway can also be reached by IPv6 directly at `fe80::200:5eff:fe00:101`.

We also utilized *outside-in* measurements to evaluate several Starlink endpoints with public IPv4 addresses where ISLs are utilized. This includes the first Starlink community gateway [1] in Unalaska, Alaska and one endpoint in Mayotte, Africa. The community gateway in Unalaska is associated with the Seattle PoP while the endpoint in Mayotte is associated with the Frankfurt PoP. We initiated the *outside-in* measurements from cloud servers closely interconnected with corresponding Starlink PoPs using ICMP-based `ping` to the public IPv4 addresses and measured the corresponding RTT.

[3]https://github.com/heistp/irtt/

Our dataset was collected continuously over the period from November 2023 to January 2024, featuring varied measurement durations for different dishes, attributable to external collaborations.

3.2 Inside-Out Measurement

For *inside-out* measurements, the information of the 13 Starlink dishes is shown in Table 1 and Table 2. Table 3 shows the obstruction map of each Starlink user dish, obtained using the open-source toolkit `starlink-grpc-tools`[4]. The sky obstruction ratio and dish alignment parameters are obtained by directly querying the Starlink dish gRPC interface using `grpcurl`[5] command with the `get_status` method.

Located in the Western Indian Ocean and having no access to any ground stations within a 5,000 km radius, the Starlink dish in Seychelles solely relies on Starlink ISLs for Internet access. It was initially associated with the Lagos PoP in Nigeria. However, the associated PoP was changed by Starlink from Lagos to Frankfurt on December 8, 2023. In Section 4, we evaluate the latency performance difference before and after the PoP change. Additionally, it is important to highlight the distinctive shape of the obstruction map for this dish in Table 3, which is attributable to the geostationary orbit (GSO) protection zone near the Earth's equator.

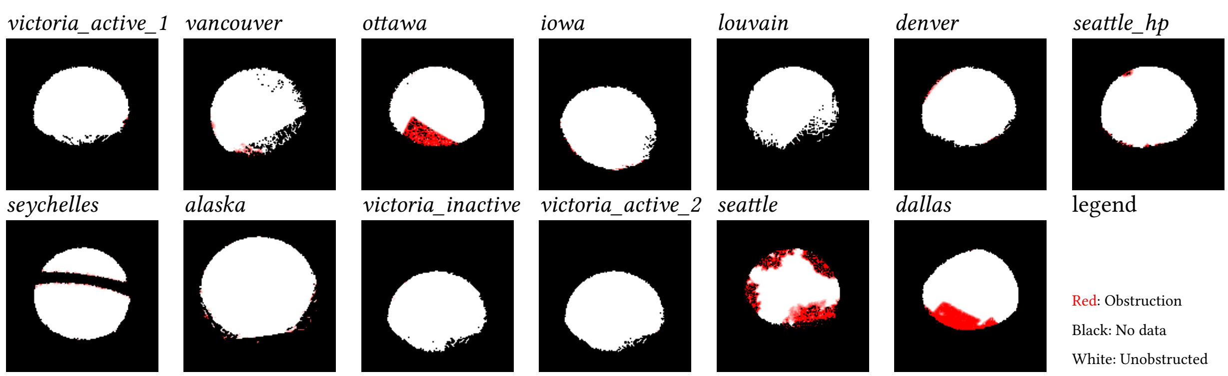
Previously, the dish gRPC interface exposes *cell_id* and *gateway_id* publicly by the `dish_get_context` method. Although this information was no longer available after firmware updates, we can still infer two dishes are in the same service cell if they have similar desired boresight azimuth and desired boresight elevation as shown in Table 2. Starlink dishes build the obstruction map when they are booted, which usually takes several hours to reach a converged state. After that, the obstruction map is usually fixed even if the dish alignment parameters are changed, which could potentially affect the satellite selection strategy and the latency performance. Since March 2024, a new `dish_clear_obstruction_map` method is available in the dish gRPC interface, which allows users to clear the obstruction map and rebuild it from scratch without

[4]https://github.com/sparky8512/starlink-grpc-tools
[5]https://github.com/fullstorydev/grpcurl

Table 2: Starlink dishes alignment parameters

Dish ID	Tilt Angle Degree	Boresight Azimuth Degree	Boresight Elevation Degree	Attitude Uncertainty Degree	Desired Boresight Azimuth Degree	Desired Boresight Elevation Degree
victoria_active_1	27.428432	1.9482158	62.51386	0.5875027	0.019116674	62.99578
victoria_active_2	29.141613	3.56736	60.99292	0.59853494	0.01841986	62.995743
victoria_inactive	25.848286	1.8109298	63.626026	0.63212514	0.018435517	62.995735
vancouver	19.208796	0.22075365	71.46458	0.71993476	-0.0004992723	70.00514
seattle	27.221867	-18.246845	63.03207	0.74343026	-19.978634	63.398506
seattle_hp	22.743135	-2.5004668	66.649994	0.3568507	-0.041417185	65.0712
ottawa	26.509708	2.7054267	63.27768	0.46602118	-0.0053449166	63.424706
denver	25.778536	1.5463749	63.665024	0.6055492	0.0016878829	63.401768
iowa	22.75151	-23.08091	66.64831	0.41341415	-22.006676	66.97447
louvain	19.727577	1.181874	69.74511	0.33187938	-0.016708912	69.97866
seychelles	13.642322	-176.24544	75.957085	0.7140684	-179.81648	76.034
alaska	18.044468	3.4209647	71.571915	1.5863512	-0.01461346	69.984245
dallas	26.613623	-26.184202	62.967274	1.3551772	-21.027962	63.640244

Table 3: Obstruction map of dishes



rebooting the dish. Tanveer et al. [13] utilized the two-line element (TLE) dataset and SGP4 algorithm to identify the satellites in the field-of-view and predict the characteristics of the satellite allocated to a user dish at a specific location and time. We placed two dishes (*victoria_active_2* and *victoria_inactive*) side-by-side on the same obstruction-free roof at a distance of 2 meters, as shown in Figure 1, to study the satellite selection strategy within the same service cell.

3.3 Outside-In Measurement

By deploying cloud servers at data centers closely interconnected with Starlink's backbone infrastructure, the terrestrial network latency can be negligible in the measurement. Most of the Starlink subscribers are only utilizing the "bent-pipe" architecture, where a single satellite hop is utilized before reaching the ground station and the gateway. As of December 2023, ISLs are utilized in certain African countries, including Kenya, Rwanda and Mozambique, where a mature terrestrial Internet backbone does not exist in Africa with limited ground stations. They are also being utilized in certain island countries in the middle of the Pacific Ocean, and Starlink Maritime services, where boats or cruise ships are equipped with Starlink dishes but have no access to nearby ground stations in the ocean.

In September 2023, Starlink deployed its first community gateway in Unalaska, Alaska, USA [1]. Different from the traditional business model where each user purchases a Starlink dish and pays a monthly subscription fee individually, the community gateway utilizes a dedicated Ka-band spectrum using parabolic antennas to provide up to 10 Gbps symmetric Internet to its customers. The last-mile connectivity to end-users is provisioned using fiber, fixed wireless or mobile wireless services by local ISPs which are responsible for operating the community gateway. By utilizing the Starlink GeoIP database[6], we identified the subnet allocated to the community gateway in Unalaska and initiated *outside-in* measurements from Akamai data centers in Seattle to the public IPv4 address of the community gateway.

4 RESULTS AND DISCUSSION

In this section, we present a high-level overview and analysis of our dataset and discuss their implications.

[6]https://geoip.starlinkisp.net

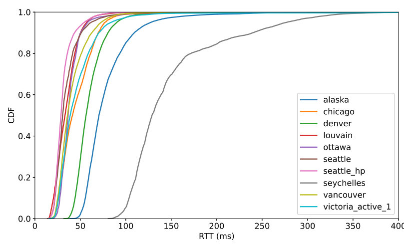


Figure 2: Active dish RTT in CDF

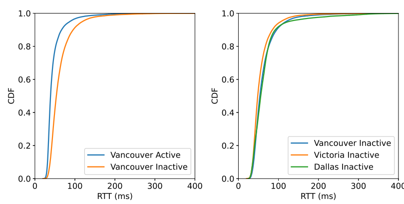


Figure 3: Inactive dish performance in CDF

4.1 Active vs Inactive Dishes

Figure 2 shows the comparison of RTT between active dishes in the *inside-out* measurements. It shows that the ISL performance is still much worse than the "bent-pipe" links, as indicated by the CDF of the *seychelles* dish. Since most Starlink satellites are deployed in the 53-degree inclination orbit, there are fewer satellites covering high-latitude regions such as Alaska. On the other hand, the *alaska* dish is associated with the Seattle PoP. There is a high probability that the traffic for this dish will land on ground stations in Alaska, which has longer distances to the Seattle PoP, leading to higher latency than other dishes associated with the Seattle PoP. Figure 2 also reveals that the *denver* dish has a higher minimum RTT compared to the remaining dishes, a discrepancy likely attributable to its association with a *Mobile Roam* plan from Canada. Consequently, the roaming traffic was assigned lower priorities than the *Standard* plan subscribers in the region. Figure 3 illustrates the performance difference for the *vancouver* dish, contingent on whether it has an active subscription. While inactive dishes are still capable of accessing the Internet at specific addresses, they are assigned lower priorities than active dishes within the access network. Additionally, the result indicates that inactive dishes, regardless of their location, exhibit similar latency performance, unaffected by varying user contention ratios at different geographical locations.

4.2 Side-by-Side Dishes

As previously shown in Figure 1, two dishes are placed side-by-side with a distance of roughly 2 meters, namely *victoria_inactive* and *victoria_active_2*. During the initialization phase following a reboot, when constructing obstruction maps, both dishes exhibit identical satellite selection strategies. This is evidenced by the white trajectory of each satellite in Figure 1, tracked in 15-second intervals. It is further confirmed by the time-synchronized latency results of both dishes, as shown in Figure 4. It shows that within the same service cell, as indicated by *Desired Boresight Azimuth* and *Desired Boresight Elevation* in Table 2, different dishes adhere to the same satellite selection strategy. Consequently, this leads to similar latency patterns across both dishes.

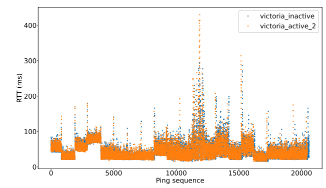


Figure 4: Side-by-side dishes latency comparison

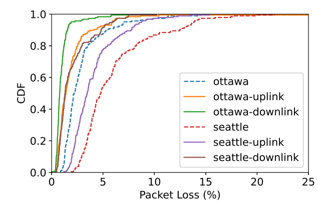


Figure 5: Hourly packet loss in CDF

4.3 Obstructions

In [10], the authors deliberately obstructed the field-of-view of a high-latitude dish to prevent it from connecting to the dense 53-degree orbital shell and reduced the number of candidate satellites to 13%. By correlating the RTT variations and the connectivity windows with TLE datasets, they found that this limitation can lead to certain connectivity windows where the dish was only served by a single satellite. In our measurements, as shown in Table 1, even though the *ottawa* dish has a higher sky obstruction ratio than the *seattle* dish, it does not necessarily have a higher time obstruction ratio, which was further reflected in the actual packet loss rates. Figure 5 shows that more packet loss events were occurring at the *seattle* dish than at the *ottawa* dish. It indicates that the sky obstruction ratio is not the only factor that affects the actual packet loss rates. Instead, it could be affected by the weather conditions, satellite selection strategy, satellite density and the user contention ratio in different service cells. On the other hand, IRTT calculates the one-way delay for both uplink and downlink. The results indicate that packet loss events are more likely to happen in the uplink. It is possibly attributable to downlink access being allocation-based, designating specific timeslots in a media access frame for a particular user terminal. Conversely, the uplink operates on either a contention-based system or a poll-randomize grant mechanism [6].

4.4 Inter-Satellite Links

The Starlink dish we have access to in Seychelles is in roaming mode since Starlink is not officially approved by the local government regulator. Initially, the associated PoP for this dish is in Lagos, Nigeria, as indicated by the DNS PTR record of its IP address, *customer.lgosnga1.pop.starlinkisp.net*. On December 8, 2023, we observed that the IP address and the DNS PTR record of this dish were

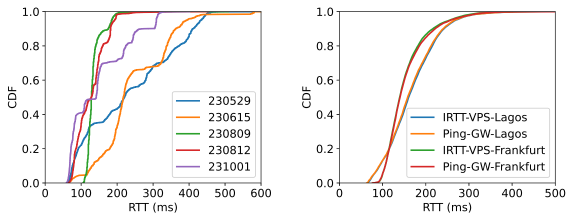


Figure 6: ISL performance at Seychelles over time in CDF

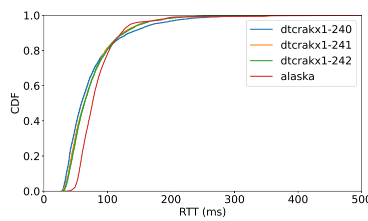


Figure 7: Community gateway vs regular user dish in Alaska

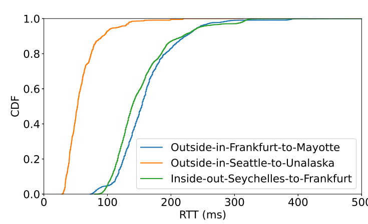


Figure 8: ISL performance at different locations

updated. The associated PoP was changed to Frankfurt, Germany, based on the DNS PTR record, *customer.frntdeu1.pop.starlinkisp.net*. It indicates that Starlink not only occasionally re-allocates subnets to different geographical regions, but also re-associates users to different PoPs. Figure 6 shows significant latency improvements from the *seychelles* dish to the Lagos PoP before the PoP change across different time slots in 2023. After the PoP change, there is a notable decrease in the CDF of RTT, yet, the minimal RTT has increased. The Lagos PoP exhibits a lower minimal RTT when traffic is routed through African ground stations in Lagos. It experiences greater latency fluctuations, attributable to a higher probability when the traffic lands on further ground stations, possibly in Europe, before reaching the Lagos PoP. Conversely, the Frankfurt PoP benefits from a denser network of ground stations resulting in lower latency variability, but suffers from a higher minimal RTT due to the longer laser link from Seychelles to Europe.

Figure 7 shows the latency performance difference between the community gateway and a regular user dish in Alaska. *dtcrakx1-x* represents three public IP endpoints in the community gateway subnet. It shows that the dedicated Ka-band link between the parabolic antennas in the community gateway to the satellites can provide lower latency compared to a regular user dish that shares Ku-band with other Starlink users in the same region. This is further evidenced by the CDF of RTT in Figure 8, which shows that the community gateway also has lower latency than regular ISL performance in Africa. Among the three endpoints in the community gateway, the CDF of RTT shows that they have similar performance over a longer period.

5 FURTHER DISCUSSION

We utilized the network latency traces in our dataset to construct a repeatable network emulation testbed for low-latency live video streaming and proposed a novel adaptive bitrate algorithm to improve the QoE of low-latency live video streaming over satellite networks [17]. It can also be applied in other video streaming testing frameworks such as *Vegvisir* [4]. Nitinder et al. [10] evaluated the performance of the Amazon Luna cloud gaming platform over Starlink networks. The results indicate that Starlink exhibits the highest user input delay and the frame rate occasionally drops to below 20 FPS. Tolouei [15] conducted a performance evaluation of the NVIDIA GeForce NOW cloud gaming platform over Starlink networks. The results also revealed that Starlink has higher latency with more variations, less stable bandwidth and more packet loss consistently across different Starlink dishes when compared with terrestrial networks. However, due to the fixed and globally synchronized 15-second handover behavior, the performance of cloud gaming can be optimized by leveraging the periodic and predictable latency patterns.

We continue to appeal to the Starlink user and research community to host RIPE Atlas probes behind their dishes, especially those who have access to dishes utilizing ISLs. We also encourage the research community to actively participate in emerging global testbeds such as [14] as we did. Additionally, we are committed to releasing monthly snapshots of our dataset to the research community.

6 CONCLUSION

In this paper, we presented LENS, a comprehensive Starlink network measurement dataset, consisting of 13 Starlink dishes worldwide with *inside-out* measurements, along with *outside-in* measurements for Starlink's first community gateway in Alaska and other endpoints utilizing ISLs in Africa. For future works, we plan to extend our dataset to other LEO satellite constellations such as OneWeb and include more diverse measurement scenarios, such as a systematic study on the impact of sky obstruction ratios and satellite selection strategies. By correlating with TLE datasets and applying time-series analysis, it could offer insights into the ISL routing and scheduling strategies. It could also be used in trace-driven simulations and emulations [8, 9] to evaluate and optimize the performance across multiple layers, including designing LEO-aware congestion control algorithms [3], improving low-latency live video streaming, and optimizing cloud gaming performance.

ACKNOWLEDGMENT

This work is supported in part by NSERC, CFI and BCKDF. This work also is not possible without our alumni and their students who hosted our Starlink dishes, and other Starlink users who allowed us to access their dishes remotely.

REFERENCES

[1] 2023. Starlink Community Gateway. https://www.starlinkinternet.info/community-gateway.

[2] 2024. RIPE Atlas - Coverage. https://atlas.ripe.net/coverage/.

[3] Xuyang Cao and Xinyu Zhang. 2023. SaTCP: Link-Layer Informed TCP Adaptation for Highly Dynamic LEO Satellite Networks. In *IEEE INFOCOM 2023 - IEEE Conference on Computer Communications*. 1–10. https://doi.org/10.1109/INFOCOM53939.2023.10228914

[4] Joris Herbots, Mike Vandersanden, Peter Quax, and Wim Lamotte. 2023. Vegvisir: A Testing Framework for HTTP/3 Media Streaming. In *Proceedings of the 14th Conference on ACM Multimedia Systems (MMSys'23)*. Association for Computing Machinery, New York, NY, USA, 403–409. https://doi.org/10.1145/3587819.3592550

[5] Bin Hu, Xumiao Zhang, Qixin Zhang, Nitin Varyani, Z. Morley Mao, Feng Qian, and Zhi-Li Zhang. 2023. LEO Satellite vs. Cellular Networks: Exploring the Potential for Synergistic Integration. In *Companion of the 19th International Conference on Emerging Networking EXperiments and Technologies (CoNEXT'23)*. Association for Computing Machinery, New York, NY, USA, 45–51. https://doi.org/10.1145/3624354.3630588

[6] Jayasuryan V. Iyer, Khasim Shaheed Shaik Mahammad, Yashodhan Dandekar, Ramakrishna Akella, Chen Chen, Phillip E. Barber, and Peter J. Worters. 2023. System and Method of Providing a Medium Access Control Scheduler.

[7] Liz Izhikevich, Manda Tran, Katherine Izhikevich, Gautam Akiwate, and Zakir Durumeric. 2024. Democratizing LEO Satellite Network Measurement. *Proceedings of the ACM on Measurement and Analysis of Computing Systems* 8, 1 (Feb. 2024), 13:1–13:26. https://doi.org/10.1145/3639039

[8] Zeqi Lai, Hewu Li, Yangtao Deng, Qian Wu, Jun Liu, Yuanjie Li, Jihao Li, Lixin Liu, Weisen Liu, and Jianping Wu. 2023. StarryNet: Empowering Researchers to Evaluate Futuristic Integrated Space and Terrestrial Networks. In *20th USENIX Symposium on Networked Systems Design and Implementation (NSDI'23)*. 1309–1324.

[9] Zeqi Lai, Hewu Li, and Jihao Li. 2020. StarPerf: Characterizing Network Performance for Emerging Mega-Constellations. In *2020 IEEE 28th International Conference on Network Protocols (ICNP)*. 1–11. https://doi.org/10.1109/ICNP49622.2020.9259357

[10] Nitinder Mohan, Andrew Ferguson, Hendrik Cech, Rohan Bose, Prakita Rayyan Renatin, Mahesh Marina, and Jörg Ott. 2024. A Multifaceted Look at Starlink Performance. In *Proceedings of the ACM Web Conference 2024 (WWW '24)*. Association for Computing Machinery, New York, NY, USA, 12 pages. https://doi.org/10.1145/3589334.3645328

[11] Jianping Pan, Jinwei Zhao, and Lin Cai. 2023. Measuring a Low-Earth-Orbit Satellite Network. In *2023 IEEE 34th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'23)*. 1–6. https://doi.org/10.1109/PIMRC56721.2023.10294034

[12] Aravindh Raman, Matteo Varvello, Hyunseok Chang, Nishanth Sastry, and Yasir Zaki. 2023. Dissecting the Performance of Satellite Network Operators. *Proceedings of the ACM on Networking* 1, CoNEXT3 (Nov. 2023), 15:1–15:25. https://doi.org/10.1145/3629137

[13] Hammas Bin Tanveer, Mike Puchol, Rachee Singh, Antonio Bianchi, and Rishab Nithyanand. 2023. Making Sense of Constellations: Methodologies for Understanding Starlink's Scheduling Algorithms. In *Companion of the 19th International Conference on Emerging Networking EXperiments and Technologies (CoNEXT'23)*. Association for Computing Machinery, New York, NY, USA, 37–43. https://doi.org/10.1145/3624354.3630586

[14] Shubham Tiwari, Saksham Bhushan, Aryan Taneja, Mohamed Kassem, Cheng Luo, Cong Zhou, Zhiyuan He, Aravindh Raman, Nishanth Sastry, Lili Qiu, and Debopam Bhattacherjee. 2023. T3P: Demystifying Low-Earth Orbit Satellite Broadband. https://doi.org/10.48550/arXiv.2310.11835 arXiv:2310.11835 [cs]

[15] Pouria Tolouei. 2023. Analysing the Performance of Cloud Gaming over a Low-Earth Orbit Satellite Network.

[16] Haoyuan Zhao, Hao Fang, Feng Wang, and Jiangchuan Liu. 2023. Realtime Multimedia Services over Starlink: A Reality Check. In *Proceedings of the 33rd Workshop on Network and Operating System Support for Digital Audio and Video (NOSSDAV '23)*. Association for Computing Machinery, New York, NY, USA, 43–49. https://doi.org/10.1145/3592473.3592562

[17] Jinwei Zhao and Jianping Pan. 2024. Low-Latency Live Video Streaming over a Low-Earth-Orbit Satellite Network with DASH. In *Proceedings of the 15th Conference on ACM Multimedia Systems (MMSys '24)*. Association for Computing Machinery, New York, NY, USA, 12 pages. https://doi.org/10.1145/3625468.3647616