Starlink Performance from Different Perspectives

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ABSTRACT

The emerging nature of low-earth-orbiting satellite constellations has brought forth an era of global connectivity. Starlink has the potential to offer a truly global, high-performant service. An obvious question arising from this is whether Starlink can replace existing terrestrial services. In this work we describe the key findings from a detailed study of the performance of Starlink, investigating both its potential and shortcomings to act as a "global ISP".

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1 INTRODUCTION

Although satellite communications have been a topic of study for several decades, it is only in the last half-decade that the notion of non-terrestrial network (NTN) directly replacing (rather than augmenting) terrestrial connectivity has gained traction. A key driver behind this change is SpaceX's Starlink satellite internet service [4]. With over six thousand satellites in the constellation, the sheer scale enables Starlink to have sufficient capacity and coverage to offer global, high-speed connectivity. Starlink is the first NTN that is a credible competitor to existing terrestrial providers. Moreover, with satellites covering the entire Earth, Starlink has the capability to bridge connectivity gaps within remote regions and position itself as a "global ISP".

To understand the global performance of Starlink and what factors impact its operations, we conducted a thorough multifaceted active and passive measurement study [2]. This poster summarizes the key learnings from our extensive measurement study which explored (i) global network performance through M-Lab and RIPE Atlas measurements, (ii) real-time Zoom and cloud gaming applications, and (iii) internal operations of the Starlink network.

Our findings reveal that Starlink is a viable competitor to terrestrial ISPs (§ 3), but that its performance is linked strongly to investment in terrestrial infrastructure (§ 4). Furthermore, the network architecture and scheduling system used by Starlink suffers from anomalies that impact end-user applications (§ 5).

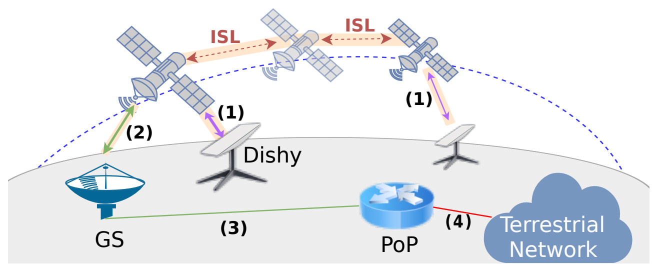

Figure 1: The "bent pipe" architecture used by Starlink, with (optional) inter-satellite links.

2 STARLINK ARCHITECTURE

The majority of Starlink's operational six thousand satellites lie within a 53°orbit, which only covers parts of the globe. Polar coverage is provided by relatively fewer satellites in 70°and 97.6°orbits.

Beyond the non-terrestrial satellites, the Starlink network utilises terrestrial elements. These include ground stations (GSs) and point-of-presences (PoPs) [1].

End users are able to reach the wider internet through the Starlink architecture shown in Figure 1.

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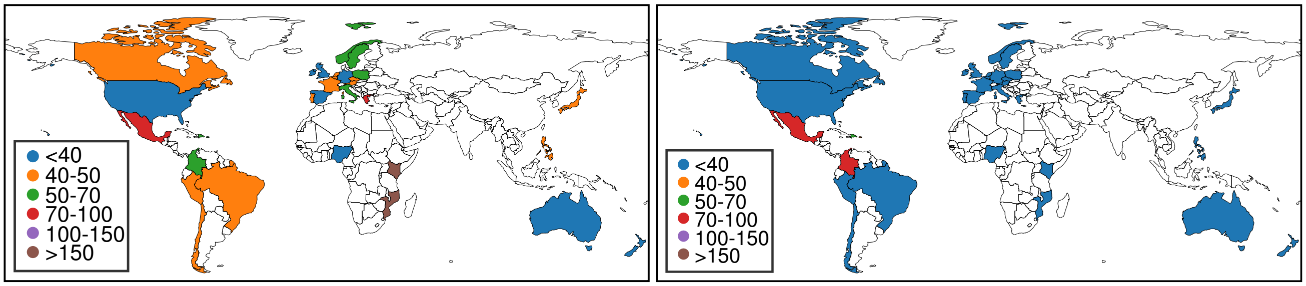

Figure 2: Median of minimum RTTs (ms) of Starlink (left) and terrestrial ISPs (right).

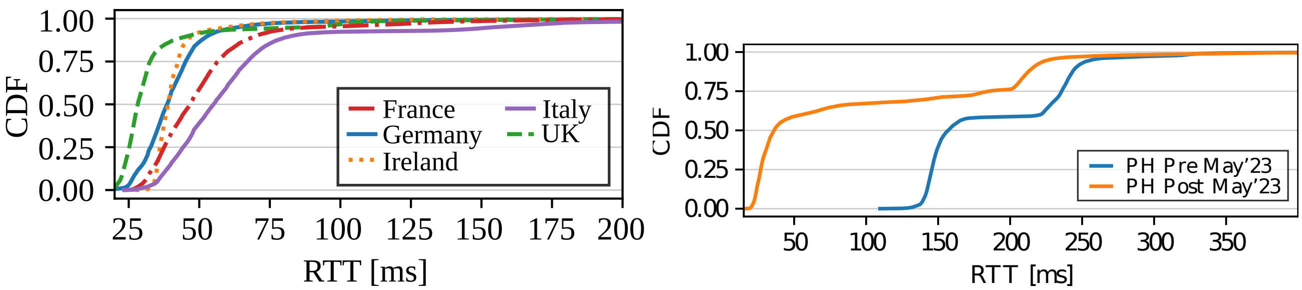

Figure 3: (a) Distribution of Starlink RTTs between select cities in Europe; (b) Starlink RTTs from a probe in the Philippines, before and after local PoP deployment.

(1) The User Terminal (also known as a "Dishy"), uplinks user traffic over the Ku-band to orbiting satellites within visible satellites from the Dishy (those above the 25°elevation and not blocked by obstructions such as trees or buildings).
(2) The receiving satellite transmits the uplinked data to a ground station within its coverage zone.
(3) The ground station forwards the uplinked data over a private terrestrial network to the local PoP.
(4) The PoP forwards the uplinked traffic to the internet.

The Dishy to satellite to ground station link forms a "bent pipe architecture", and requires that both the Dishy and ground station lie within the coverage zone of the satellite providing the "bent pipe" route, something not always possible, particularly in remote regions. To maintain connectivity, Starlink satellites form peer-to-peer links (ISLs), extending the "bent pipe" to connect to farther ground stations.

3 COMPETITIVE TERRESTRIAL PERFORMANCE

A key finding of our study is that Starlink provides a global service that is competitive to terrestrial ISPs. As shown in Figure 2, in the vast majority of locations, Starlink provides a service that is comparable or almost-comparable to that of terrestrial ISPs. More broadly, there are very few locations at which the performance drops below a level of service that would be deemed acceptable.

Considering specific applications, Starlink remains competitive with terrestrial ISPs for demanding real-time applications of video calling (Zoom) and cloud gaming (Amazon Luna). Both of these applications require low-latency and high-bandwidth; they differ in that cloud gaming performance largely depends upon round-trip latency and downlink bandwidth, while for video calling both uplink and downlink bandwidth play an important role. We found that the performance was largely equal between terrestrial (fibre and cellular) and Starlink, although for cloud gaming Starlink exhibited better performance than cellular 5G.

Indeed, when specifically considering remote regions, we observe that the service offered by Starlink well exceeds that of incumbent terrestrial providers. Specifically, we look at Reunion Island, a small island off the east coast of Madagascar. The island receives terrestrial connectivity through two submarine-laid cables, routing traffic to either Asia or South America. Despite no ground stations or PoPs being hosted on the island, Starlink's round-trip latencies (around 150ms) are lower than that of the alternative terrestrial service (around 210ms), thanks to Starlink's ability to route traffic directly between satellites using ISLs. This case study demonstrates Starlink's ability to connect remote regions with a quality of service higher than that of current terrestrial offerings.

4 DEPLOYMENT-DEPENDENT PERFORMANCE

Despite the positive findings § 3, our study also revealed significant variations in Starlink performance across different

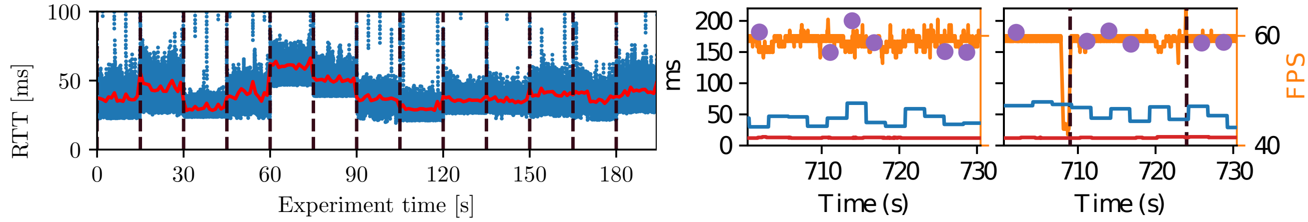

Figure 4: (a) Fine-grained RTT measurements, with the 15-second reconfiguration intervals overlaid, (b) Cloud gaming over 5G (left) and Starlink (right), with the reconfiguration intervals overlaid.

geographical regions. Taking Europe as a case study (Figure 3a), we observed that certain cities (Dublin, London, Berlin) exhibited good performance on-par with the continental US, while other cities (Rome, Paris) experienced worse performance. Further analysis revealed a correlation between the distance to the nearest PoP and the performance. The UK and Germany have a local PoP, whilst connections from Italy and France are routed to a PoP in a neighboring country.

This finding was investigated further through a longitudinal case study of the Philippines, where we observed the impact of the deployment of a new PoP in May 2023. As shown in Figure 3b, before the in-country PoP was deployed, Philippines-based users accessing local services observed high latencies as the Starlink traffic was received by ground stations in Philippines but was then routed to the nearest PoP in Japan via undersea cable, travelling back to the Philippines to the local server. After PoP deployment in the Philippines, this non-optimal terrestrial routing route was cut short and latencies noticeably improved.

This finding reveals that NTNs such as Starlink are not a silver bullet to allow ISPs to avoid costly investments in ground infrastructure. Such investments are necessary, albeit at a lesser scale, with NTNs in order to ensure acceptable and consistent performance. Furthermore, investment is also required in the NTN infrastructure, i.e. the satellites. We additionally observed performance degradation for users at high latitudes due to the smaller number of satellites that are able to serve these users.

5 GLOBAL SCHEDULING ARTEFACTS

To understand the role and impact that the internal mechanisms of Starlink have on the end-user performance, we conducted a set of experiments aimed at peeling-back the black box that is Starlink.

Our findings revealed that the scheduling system used by Starlink, based around 15-second reconfiguration intervals, has an observable impact on the experienced performance. Figure 4a shows fine-grained latency measurements over a three minute window. Overlaying the reconfiguration intervals revealed correlations.

We observe that the latency remains relatively stable within each reconfiguration interval, but can fluctuate significantly at the boundary between intervals. Extending this experiment to throughput, we observed significant drops in throughput at every reconfiguration interval boundary.

The general understanding within the community is that Starlink performs satellite handovers at these fixed 15 second intervals, which is the primary cause of performance degradation. Indeed, the FCC filing [3] supports this hypothesis, describing the intervals as "handing off connections between satellites" However, further experiments whereby we controlled the setup to ensure the Dishy remained connected to a single satellite for the experiment duration, revealed that the anomolies in both latency and throughput remained.

While the performance issues described in § 4 can be mitigated through investment in the ground and space infrastructure, these performance fluctuations are integral to the scheduling system used by Starlink, and therefore are far more deeply rooted and fundamental to the network design.

Further experiments revealed these anomlies have a tangible impact on the application performance of Starlink. Revisiting our experiments with Zoom and Amazon Luna, we observed corresponding fluctuations in their performance. The former experienced shifts in the one-way-delay while the latter experienced occasional drops in the frame rate (shown in Figure 4b), both of these anomalies coinciding with the boundary between reconfiguration intervals. Perhaps more significantly, we noticed changes in the amount of error correction packets being sent, and again these changes aligned with the interval boundaries.

REFERENCES

[1] Case No. 2021-00002. 2021. *Application of Starlink Services*. https://psc.ky.gov/pscecf/2021-00002/kerry.ingle%40dinslaw.com/01042021010318/Application_-_Designation_as_ETC.PDF Accessed on 2023-05-24.

[2] Nitinder Mohan, Andrew E. Ferguson, Hendrik Cech, Rohan Bose, Prakita Rayyan Renatin, Mahesh K. Marina, and Jörg Ott. 2024. A Multifaceted Look at Starlink Performance *(WWW '24)*. https://doi.org/10.1145/3589334.3645328

[3] SpaceX. 2021. PETITION OF STARLINK SERVICES, LLC FOR DESIGNATION AS AN ELIGIBLE TELECOMMUNICATIONS CARRIER. https://www.fcc.gov/ecfs/search/search-filings/filing/1020316268311.

[4] Starlink. 2024. High-speed Internet Around the World. https://www.starlink.com/.