
Review #693A

Overall merit

3. Weak accept

Reviewer expertise

2. Some familiarity

Paper summary

This paper presents a platform for collecting starlink network metrics together with multiple sensor data. Authors open source the platform and dataset, which is a fine-grained, multi-modal dataset for mobile satellite communication research. The platform includes a robot dog, starlink mini terminal, and synchronized sensors, Lidar for environment context, fish eye camera for sky visibility, IMU and GPS for motion and location info. The paper also presents two case studies on the impact of movement velocity and environmental obstructions, and discuss research opportunities.

Comments for authors

Strength:

1. The platform and associated dataset fills a gap -- starlink network metrics for terrestrial mobile applications. The dataset is labeled with synchronized motion data and environmental context, which is not seen in prior work/dataset.
2. The dataset covers diverse sensor information to understand the impact of motion, environmental obstructions. It also covers several types of urban environments and motion speed.
3. I appreciate that authors open source both the platform and dataset, so that other community members can replicate and contribute.

Weakness:

1. My main concern is that the quantity and diversity of data is relatively limited. Total duration is only 7 hours. It is not clear whether the collection happens in one day. The diversity of data across different days can be important, due to factors like weather. The location of data collection is also only one area in London. The authors mentioned data collection is on-going to expand the dataset. It would be great to see the expanded dataset.
2. The author mentioned "sub-millisecond alignment accuracy" for sensor data. It seems to mean alignment with GPS clock time. This is different from alignment between sensors. Authors should clarify this and provide information about actual time mismatch between sensors.
3. Authors should consider provide more details for sensor specifications, like FPS for each sensor and metric, and details about when and how data are collected. At the moment of my review, the project website on github is not released yet.

Review #693B

Overall merit

4. Accept

Reviewer expertise

2. Some familiarity

Paper summary

The authors build a wheeled "Starlink Robot" that couples a Starlink Mini terminal with an upward fisheye camera, 360-degree LiDAR, IMU, and GPS, all time-synchronized on an onboard NUC. They release (i) the mechanical/electrical design and (ii) a 7-hour, 120 GB multimodal dataset collected while driving through open, semi-occluded, and heavily occluded urban paths. Initial analyses compare RTT and throughput under two velocities and three obstruction regimes, showing that velocity matters little but canopy occlusion causes sharp latency changes.

Comments for authors

This paper introduces a small, wheeled robot that carries a Starlink Mini terminal alongside a fisheye sky camera, 360-degree LiDAR, IMU, and GPS, all time-synchronised on an onboard NUC. The authors release both the hardware design and a seven-hour, 120 GB dataset that couples network traces with rich environmental context gathered while the robot moves through open plazas, tree-lined paths, and dense urban corridors. Their preliminary analysis shows that walking-speed motion leaves latency unchanged and canopy occlusion triggers sharp and repeatable RTT spikes. They attribute the latter to reduced satellite visibility and forced handovers.

What makes the work stand out is not the idea of measuring Starlink in motion but the way the authors marry Starlink metrics to ground-truth sensing. Previous vehicle trials log only GPS and speed with no reasoning behind missing data. Here, synchronized fisheye imagery and LiDAR point clouds reveal exactly when and how trees, buildings, or bridges block the view of the sky. The platform also targets a pedestrian-scale regime (0.1–2 m/s), filling a gap between stationary terminals and high-speed vehicular tests, and the openly released dataset will enable researchers to train models that predict link quality directly from visual or 3-D cues.

Sub-millisecond time alignment via GPS and hardware triggers is believable, though the paper should include the clock-sync code. Throughput probing every thirty seconds captures long-term trends. Releasing the raw packet traces would also be beneficial to the community. The evaluation separates the effects of speed from those of occlusion; however, only two velocities are tested. LTE is absent as a baseline, and statistical confidence intervals are missing.

The paper offers a well-engineered platform and a uniquely rich dataset. It also offers the beginnings of an analysis that already introduces useful insights about Starlink's sensitivity to occlusion. The work is incremental with respect to prior mobile studies, but the addition of multi-modal sensing is novel.

Review #693C

Overall merit

3. Weak accept

Reviewer expertise

3. Knowledgeable

Paper summary

The paper presents Starlink Robot, a mobile robotic platform integrating a Starlink Mini terminal with synchronized sensing (fisheye camera, Livox LiDAR, IMU, GPS) to characterize satellite internet performance under motion and occlusion. The authors describe the hardware and software architectures, provide seven hours of multi-modal data collected in urban London ($\approx 25,000$ RTT samples, 630,000 LiDAR frames, 378,000 images), and demonstrate preliminary findings on how velocity and environment affect latency. They release both the platform design and dataset to enable motion-aware protocol development, connectivity-aware path planning, handover optimization, and environment-adaptive communication strategies.

Comments for authors

Strengths:

- + The paper presents a mobile testbed, first systematic integration of Starlink Mini with a robotic base and a rich sensor suite for real-world satellite performance measurements under controlled motion.
- + The proposed approach enables detailed correlation between physical context and communication quality through multi-modal recordings (network metrics, 3D point clouds, fisheye imagery, IMU/GPS) with sub-millisecond synchronization.
- + The paper is well-written with detailed hardware and software descriptions, aiding reproducibility. Weaknesses:
 - Data is confined to one geographic region (urban London) and two speed regimes (0.8 m/s, 2.0 m/s), limiting generalizability to other environments (rural, maritime) and motion profiles (vehicular, aerial).
 - Absence of run counts, confidence intervals, or error bars for measured RTT distributions; no baseline comparisons (e.g., stationary Starlink or LTE under identical conditions).
 - Reliance on a reverse-engineered gRPC interface without details on versioning or script availability. Minimal discussion of dataset organization, naming conventions, and annotation schemas.
 - No evaluation of power consumption or battery life. Suggestions:
 - Extend velocity experiments to include additional speeds (e.g., 5 m/s vehicular) and multiple geographic settings to validate findings across diverse satellite elevation angles and obstruction patterns.
 - Include a stationary Starlink Mini baseline and a terrestrial LTE comparison to contextualize the magnitude of mobility-induced performance changes.
 - Statistical analysis needs to be more rigorous. For example, report the number of runs per speed and environment; include mean \pm STD or confidence intervals for RTT and throughput measurements to demonstrate repeatability.
 - Dataset needs proper documentation. Provide a clear data repository structure with naming conventions, calibration metadata, and sample scripts for parsing ROS bags, CSV logs, and HDF5 outputs.
 - Evaluation of power consumption or battery life under continuous sensing and active probing is needed. Lack of discussion on computational/storage scalability for prolonged or resource-constrained deployments makes the paper weak.

Review #693D

Overall merit

3. Weak accept

Reviewer expertise

2. Some familiarity

Paper summary

This paper presents a platform called "Starlink Robot", which integrates multiple sensors, including LiDAR, IMU, and GPS, to study mobile satellite communication. Other than deployment, the authors also share a multi-modal dataset (7hours, 120 GB) with network metrics, motion data, and environmental scenarios. This paper is claimed to be the first open platform and dataset for systematic study of mobile satellite communication under real-world mobility.

Comments for authors

Strengths:

- Open-sourcing both the dataset (claimed as the first dataset to systematically combine satellite performance with motion and environment context) and the platform has the potential to benefit the community.
- Preliminary findings, while simple, demonstrate the feasibility and utility of the platform.
- Interesting topic, which can be useful to research communities focusing on satellite internet for mobile and IoT applications.
- Platform design is clearly described, with thoughtful synchronization across heterogeneous data sources.

Weaknesses:

- The platform (as one major part of the contribution) seems merely an incremental integration of off-the-shelf components; more methodological novelty is expected.
- Dataset size is arguably modest (7 hours, 120GB) and may raise concerns while serving as a strong and generalizable benchmark.
- Preliminary analyses mostly confirm expected phenomena (obstructions degrade performance, open sky is stable).
- Fit with SenSys is not perfect: the work feels closer to a dataset announcement than a system or sensing innovation.
- Reproducibility may be limited due to reliance on costly hardware (Unitree GO2, LiDAR).

More Detailed Questions to Authors:

1. The dataset currently contains ~7 hours of data collected in London at pedestrian speeds. How do you plan to expand its scale and diversity (e.g., different geographies, mobility modes such as cars, drones, or maritime platforms) so it can serve as a broader benchmark for the community?
2. Beyond confirming expected patterns (e.g., occlusion causes performance degradation), what concrete new research questions can only be answered with your dataset? E.g., can you demonstrate that it enables the design of predictive models or adaptive protocols that could not be studied with existing stationary datasets?
3. The hardware setup (Unitree GO2, LiDAR, Starlink Mini) is costly and not widely accessible. Can you propose a lower-cost, reproducible alternative (e.g., simplified mobile platforms or sensor configurations) that would allow more researchers to replicate or extend your work?
4. Can you provide at least one detailed case study showing how your dataset leads to actionable insights (e.g., a model for handover prediction, a connectivity-aware path planning algorithm) rather than general observations?
5. How do you see this dataset fitting into the SenSys community specifically, which values sensing innovations and system-level contributions? Could you outline how your dataset supports future sensing system research rather than only networking studies?

Review #693E

Overall merit

3. Weak accept

Reviewer expertise

3. Knowledgeable

Paper summary

This is a data set (short) paper. The authors implemented a robot-based platform connecting a Starlink model and a number of sensors (visual and motion) to associate the satellite communication quality to a number of factors — mobility and obstruction.

Comments for authors

Strength

- + satellite communication drawing a growing customer base a hot topic
- + HW/SW effort respectable
- + nice initial data set

Weakness

- the mobility range a little limited
- the routes and environment limited

Detailed Comments

- Thank you for submitting to SenSys. The system effort and the data collected will benefit works that aim at improving mobile satellite communication. This is a hot topic as small form-factor satellite receivers are commercially available and growingly affordable, making mobile satellite communication a practical option for areas that cellular deployment is limited.
- The hardware implementation and data timestamp alignment are respectable.
- The data collection effort is nice. It appears a little limited in the moving speed range (currently the walking speed) and the environment/routes (open and tree-covered space only). It'd be nicer if a higher variability of moving speed and 'sky availability' measurements are available.
- One potential research problem the data set may benefit from is — how one switch seamlessly between cellular and satellite network for true ubiquitous communication on earth (cost-effective mobile communication?). A known worthy use of Starlink is mobile communication in remote areas where dense cellular deployment is expensive. With data collected from urban and remote areas, one'll be able to quantify/optimize the cost.

@A1 Reviewer E · Sep 20

The paper is discussed online and the decision is a condition accept. In short, we find the work timely, the data set rich, and the effort respectable. However, as a field work and data set paper, we seek (1) a description detailing the platform HW specs and settings, (2) a description detailing the organization of code and data will be made publicly available, and (3) a companion site hosting the the descriptions, code, and data. Please address these 3 concerns to remove the condition before the revision deadline.

If time permits, you are encouraged to address additional comments/ suggestions in the individual reviews as well.

@A2  Boyi Liu (Author) · Sep 30

Dear Shepherd,

We would like to express our sincere gratitude for your time and effort in shepherding our paper, and for the valuable feedback provided by you and the reviewers. We are very pleased with the conditional acceptance decision and fully committed to addressing all the concerns raised to ensure our work meets the high standards of SenSys.

We understand that the three primary conditions for removing the conditional acceptance are critical to the quality and impact of our work as a field work and data set paper. We would like to assure you that we will fully address each of them:

1. Platform Hardware Specifications and Settings: We will provide detailed specifications of all hardware components (robot, sensors, computing) and software tools used for data collection, including key configurations such as sampling rates, resolution, field-of-view, and software versions to ensure full reproducibility.
2. Code and Data Organization: The repository will include comprehensive documentation detailing the dataset's directory structure, file naming conventions, and data formats (ROS bags, CSVs, HDF5). We will provide well-commented sample scripts for parsing, synchronizing, and visualizing the multi-modal data, along with complete documentation of our data collection methodology.
3. Companion Website and Public Repository: We will launch a fully functional GitHub repository before the revision deadline, serving as the project's companion site. This site will host all data collection and analysis code, comprehensive documentation, and the complete dataset (via an accessible link).

Should any of the above content conflict with page limitations, it will be comprehensively listed on the repository homepage to ensure complete transparency and reproducibility.

Beyond these primary conditions, we will also carefully address the additional suggestions from the individual reviews to further strengthen the paper. Please find our detailed revision plan attached, which provides a comprehensive overview of all planned changes

and our specific responses to each reviewer's comments.

We are confident that the revised version will fully meet the requirements for acceptance, and we look forward to your feedback.

Thank you once again for your guidance and support!

Best regards, The Authors of Submission #693

 RevisionPlan.pdf (176kB)

@A3 Shepherd · Oct 7

Thank you. The plan sounds good. Please go ahead and revise accordingly.

@A4  Boyi Liu (Author) · Oct 27

Dear Shepherd,

We are pleased to submit the revised version of our manuscript, Submission #693, "The Starlink Robot: A Platform and Dataset for Mobile Satellite Communication," for SenSys 2026.

We sincerely thank you and the reviewers for the constructive feedback and for the conditional acceptance of our work. We are very grateful for your guidance during the shepherding process.

We have carefully addressed all concerns raised, including the three primary conditions for acceptance and all additional reviewer suggestions outlined in the revision plan.

To facilitate your review, all significant changes in the revised manuscript have been marked with **blue text**.

As detailed in the following pages of this response letter, we have outlined our specific implementation for **each of the planned revisions (Planned Revision 1 through 8)**.

We have worked diligently to ensure these revisions thoroughly address all feedback. We hope the revised manuscript now meets the standard for publication at SenSys 2026.

Attached files are Response File, Revised Paper with blue highlight and Revised Paper.

Thank you again for your consideration and guidance.

Sincerely,

Authors of Submission #693

 Response File.pdf (97kB)

 Revised Paper with blue highlight.pdf (12.2MB)

 Revised Paper.pdf (12.2MB)

@A5 Shepherd · Oct 30

Dear Authors, Thank you for considering our comments. Your revisions look excellent, and congratulations once again.

Revision Plan and Response to Comments

Submission #693, SenSys 2026

Revision Plan

We sincerely thank the reviewers and shepherd for their constructive feedback on our work. We are committed to addressing all concerns raised during the shepherding process. Our revision plan focuses on the three primary conditions for acceptance and additional reviewer suggestions:

Primary Conditions:

- **Companion Website and Public Repository:** We will launch a fully functional GitHub repository, serving as the project's companion site. This site will host all data collection and analysis code, and the complete dataset (via an accessible link).
- **Code and Data Organization:** The repository will include comprehensive documentation detailing the dataset's directory structure, file naming conventions, and data formats (ROS bags, CSVs, HDF5). We will provide well-commented sample scripts for parsing, synchronizing, and visualizing the multi-modal data.
- **Data Collection Methodology and Tools:** We will document the complete data collection workflow, including the open-source tools used, visualization tools for real-time monitoring, and step-by-step procedures for data acquisition and synchronization.
- **Hardware and Software Specifications:** We will provide detailed specifications of all hardware components (robot, sensors, computing) and software tools used for data collection, including key configurations (e.g., sampling rates, resolution, field-of-view, software versions) to ensure full reproducibility.

Should any of the above content conflict with page limitations, it will be comprehensively listed on the repository homepage.

Additional Improvements:

- **Expand Dataset:** We will expand the public dataset with over 5 hours of new data, incorporating recordings under different mobility speeds and diverse occlusion scenarios at various times of day to increase diversity. Additionally, we have partnered with new research groups to jointly contribute to and maintain this dataset as a continuously evolving community resource.
- **Add Statistical Rigor:** All performance evaluation contents will be updated to include rigorous statistical analysis, such as mean values and confidence intervals.
- **Strengthen Novelty and SenSys Fit:** We will add discussion of several promising application scenarios enabled by our multi-modal sensing platform at the end of the paper, directly

demonstrating how the platform supports novel sensing research relevant to the SenSys community.

- **Add Power Consumption Analysis:** We will include descriptions of the platform's overall power consumption and operational endurance (battery life) during data collection missions within the existing system description sections.

We summarize the comments and our responses in the following:

Comment 1 (Reviewers A, C, D, E): The quantity, diversity, and scale of the dataset are limited (7 hours, limited speeds/environments).

- **Response:** We thank the reviewers for this crucial feedback and share their vision for a more extensive and diverse dataset. Our goal for this project has always been to establish a foundational, living dataset that grows over time with contributions from our team and the broader research community. To that end, we have been actively collecting data since our initial submission. We are pleased to report that the public dataset will now be enhanced with several hours of new recordings that directly address the reviewers' suggestions, including experiments under higher-speed mobility profiles and across more diverse occlusion scenarios at different times of the day. We will explicitly position the repository as a continuously updated resource and actively encourage collaboration. We have already partnered with research groups at institutions such as the University of Virginia to jointly contribute to and maintain the dataset, expanding its geographic and environmental diversity. We believe this collaborative and continuous enrichment approach is the most effective way to maximize the dataset's long-term value and impact for the SenSys community.

Comment 2 (Reviewers B, C): The experimental analysis lacks statistical rigor (no confidence intervals, run counts) .

- **Response:** We agree this is an excellent point that will significantly improve the paper. In the revised version, all performance-related figures and claims will be updated with rigorous statistical analysis, including mean values and confidence intervals to demonstrate repeatability.

Comment 3 (Reviewer E, A, B, C, D): The paper requires comprehensive documentation, a public repository for the dataset and code, and details for reproducibility.

- **Response:** We fully agree and will make reproducibility a central focus of our revision, as mandated by the conditional acceptance. Before the revision deadline, we will launch a public GitHub repository to serve as a companion site. This repository will contain detailed hardware

and software specifications, documentation of our complete data collection methodology (including open-source tools, visualization workflows, and step-by-step procedures), the complete dataset with clear documentation on its structure and format, and all of our ROS-based collection software and Python analysis scripts required to reproduce the results. Should page limitations prevent including all details in the paper, comprehensive information will be provided on the repository's homepage.

Comment 4 (Reviewers A, C): The paper needs more technical details on time synchronization, sensor specifications, the gRPC interface, and power consumption.

- **Response:** We thank the reviewers for noting these omissions. We will enhance the paper's clarity by elaborating on our "sub-millisecond alignment" method, describing how the GPS PPS signal serves as a master clock for timestamping. As noted in our primary conditions, comprehensive hardware and software specifications, along with detailed data collection methodology, will be documented in the repository. We will also clarify that we use a well-established open-source tool to query the Starlink terminal's gRPC interface. Finally, descriptions of the platform's power draw and battery life will be integrated into the existing system description sections.

Comment 5 (Reviewer D): The contribution seems like an incremental integration, and the fit with SenSys could be stronger by showing more novel sensing research enabled by the platform.

- **Response:** We appreciate this constructive feedback on positioning our work. To better align with the SenSys community, we will add discussion of several promising application scenarios at the end of the paper that demonstrate novel sensing capabilities enabled by our platform. For example, we will discuss how synchronized LiDAR and fisheye data could enable predictive communication quality sensing, where physical environment features are used to anticipate network performance changes. We will also reframe the paper's narrative to emphasize our contribution as a system that turns the physical environment into a predictable variable for communication networks, highlighting how our platform enables new research at the intersection of sensing and networking.

Response File of Paper #693

Authors of #693

Dear Shepherd,

We are pleased to submit the revised version of our manuscript, Submission #693, "The Starlink Robot: A Platform and Dataset for Mobile Satellite Communication," for SenSys 2026.

We sincerely thank you and the reviewers for the constructive feedback and for the conditional acceptance of our work. We are very grateful for your guidance during the shepherding process.

We have carefully addressed all concerns raised, including the three primary conditions for acceptance and all additional reviewer suggestions outlined in the revision plan.

To facilitate your review, all significant changes in the revised manuscript have been marked with **blue text**.

As detailed in the following pages of this response letter, we have outlined our specific implementation for **each of the planned revisions (Planned Revision 1 through 8)**.

We have worked diligently to ensure these revisions thoroughly address all feedback. We hope the revised manuscript now meets the standard for publication at SenSys 2026.

Thank you again for your consideration and guidance.

Sincerely,

Authors of Submission #693

October 25, 2025

Planned Revision 1:

We will launch a fully functional GitHub repository, serving as the project’s companion site. This site will host all data collection and analysis code, and the complete dataset (via an accessible link).

Implementation:

To ensure long-term accessibility and consistency, we unified all companion materials under a dedicated project homepage at <https://starlinkrobot.github.io>. This site now serves as the central repository for the dataset, analysis code, video demonstration, and technical documentation, satisfying the reproducibility and transparency objectives described in the revision plan.

- In the **Abstract**, we updated the repository link to the new companion site of <https://starlinkrobot.github.io> to reflect the finalized project location.
- In **Section 4**, we revised the final sentence to specify that both the dataset and analysis code are hosted on the companion site, which also provides documentation and ongoing updates.

Planned Revision 2:

The repository will include comprehensive documentation detailing the dataset’s directory structure, file naming conventions, and data formats (ROS bags, CSVs, HDF5). We will provide well-commented sample scripts for parsing, synchronizing, and visualizing the multi-modal data.

Implementation:

We revised the **Data Format and Organization** subsection in Section 4 to fully describe the structured organization of the dataset and to reference the new companion site resources. The new paragraph explains how raw sensor data (LiDAR, fisheye camera, IMU, GPS) are stored in ROS bag format, how processed communication metrics are exported as CSV files, and how all synchronized data are consolidated into HDF5 for analysis.

It further clarifies that the companion site at <https://starlinkrobot.github.io> now provides detailed documentation of the dataset directory hierarchy, naming conventions, and data schema, together with newly added example scripts that demonstrate data parsing, synchronization, and visualization workflows introduced in this revision.

As part of this revision, we supplemented the companion site with the following files to enhance code and data organization:

- `docs/data_structure.md`: Describes the dataset hierarchy, naming conventions, and mapping between ROS, CSV, and HDF5 data.
- `docs/file_formats.md`: Defines all data fields and units for each sensing modality.
- `scripts/parse_rosbag.py`: Parses raw ROS bag files and extracts synchronized measurements into standard CSV/HDF5 outputs.
- `scripts/sync_datasets.py`: Implements GPS-based timestamp alignment across heterogeneous sensor streams.
- `scripts/visualize_metrics.py`: Visualizes communication and motion metrics, reproducing the quantitative figures presented in the paper.

These newly introduced files and documentation updates were added in direct response to the revision plan requirement for comprehensive code and data organization, ensuring that the repository now provides complete guidance for data access, parsing, and analysis.

Planned Revision 3:

We will document the complete data collection workflow, including the open-source tools used, visualization tools for real-time monitoring, and step-by-step procedures for data acquisition and synchronization.

Implementation:

To strengthen this section, we incorporated the open-source tool **LEOViz** into our system description, dataset, and acknowledgements. We revised Section 3.2 (*Software Architecture*) to explicitly describe how LEOViz parses Starlink’s gRPC status interface and provides 1 Hz satellite tracking, elevation, and signal-quality updates for real-time visualization and logging. Section 4 (*Dataset Description*) now clarifies that all satellite-tracking and obstruction-visualization data are collected using LEOViz, ensuring precise synchronization between constellation geometry and communication metrics. We also added a formal acknowledgment of the LEOViz developers for their contribution to this workflow.

To accompany these textual revisions, the companion site (<https://starlinkrobot.github.io>) now includes:

- `docs/leoviz_integration.md`: The file explains LEOViz setup, configuration, and data export pipeline.
- `scripts/run_leoviz.sh`: The file launches LEOViz with logging enabled for automated satellite data collection.
- `examples/leoviz_output_parser.py`: The file parses LEOViz JSON logs and aligns them with communication metrics.

These additions fulfill the revision requirement by fully documenting the data collection methodology and the integration of open-source visualization tools.

Planned Revision 4:

Hardware and Software Specifications: We will provide detailed specifications of all hardware components (robot, sensors, computing) and software tools used for data collection, including key configurations (e.g., sampling rates, resolution, field-of-view, software versions) to ensure full reproducibility.

Implementation:

We revised **Section 3.1 (Hardware Architecture)** to clarify and complete the description of the system hardware and its integration.

The updated text specifies that the platform is built upon the *Unitree Go2* wheeled version and replaces the previous aluminum frame with a 3D-printed mounting structure. This mount supports the Starlink Mini terminal, the Livox Mid-360 LiDAR (now specified with a **360° field-of-view at 25 Hz**), and the upward-facing fisheye camera (specified with a **185° FoV, 15 Hz** sampling rate, and **1920x1080** resolution).

The revised section now explains the connection and power architecture in detail: the Starlink Mini connects to the onboard Intel NUC via Ethernet, while a DC-DC converter regulates the robot’s 24 V power

supply to meet the 12 V input requirement of the terminal.

We also detailed the **Computing Platform** subsection, specifying the Intel NUC running **Ubuntu 18.04 with ROS Noetic** as the central processing and synchronization node.

The section further clarifies that the platform does not include a separate IMU or GPS module. Motion and localization data are instead obtained from the robot's internal SLAM estimator and the Starlink terminal's built-in positioning output. These sources are synchronized through the NUC's system clock, which provides sub-millisecond temporal alignment across sensing and communication modalities.

This revision replaces earlier generic descriptions with a precise, reproducible account of hardware components, **their key configurations**, connectivity, and timing coordination.

To support this update, the companion site at <https://starlinkrobot.github.io> now includes documentation and scripts.

Together, these revisions fulfill the requirement for comprehensive hardware and software specifications and ensure that the paper and repository jointly present a complete and verifiable system description.

Planned Revision 5:

Expand Dataset: We will expand the public dataset with over 5 hours of new data, incorporating recordings under different mobility speeds and diverse occlusion scenarios at various times of day to increase diversity. Additionally, we have partnered with new research groups to jointly contribute to and maintain this dataset as a continuously evolving community resource.

Implementation:

The companion dataset hosted at <https://starlinkrobot.github.io> has been expanded and reorganized to include additional recording sessions collected under more diverse operational conditions. New data have been added for high-speed mobility profiles and during late-afternoon periods to capture varying illumination and link-quality dynamics. Additional segments covering different levels of environmental occlusion were also included to improve scene diversity and robustness of future analysis. All newly added data are documented and indexed in the repository for easy access, and the dataset will continue to grow as more sessions are collected.

The project has also initiated extended collaboration with the *Norwegian University of Science and Technology (NTNU)* and continues cooperation with the *University of Virginia*. These collaborations will contribute additional data from different geographical and environmental settings, ensuring that the dataset remains an evolving community resource.

This update addresses the review feedback regarding dataset quantity and diversity while maintaining the reproducibility and accessibility principles outlined in the original plan.

Planned Revision 6:

Add Statistical Rigor: All performance evaluation contents will be updated to include rigorous statistical analysis, such as mean values and confidence intervals.

Implementation:

We refined the reporting in the evaluation section using the data already collected, without adding new trials. Specifically, we augmented **Section 5** as follows:

- **Section 5.1 (Impact of Movement Velocity):** For each velocity condition, we now report round-trip time (RTT) as a concise numerical summary (*mean* with 95% confidence interval) alongside the existing narrative. These values are computed directly from the same measurement traces used to produce the figures.
- **Section 5.2 (Impact of Environmental Obstructions):** For representative segments (open areas vs. tree-covered paths), we report RTT summaries in the same format (*mean* with 95% confidence interval) to quantify the observed variability under obstruction.
- **Figure captions:** For the plots that illustrate these conditions (e.g., Figs. 9, 10, 12, 15), we added a brief parenthetical note listing the corresponding numerical summaries to complement the visual trends. The figures themselves were not reformatted.

These additions provide quantitative support for the conclusions while keeping the presentation concise and consistent with the original layout.

Planned Revision 7:

Strengthen Novelty and SenSys Fit: We will add discussion of several promising application scenarios enabled by our multi-modal sensing platform at the end of the paper, directly demonstrating how the platform supports novel sensing research relevant to the SenSys community.

Implementation:

We revised **Section 6 (Research Opportunities)** by consolidating it into a single concise paragraph that highlights opportunities most relevant to the *SenSys* community. The updated text emphasizes: (i) motion-aware networking using synchronized RTT and SLAM-derived motion traces; (ii) connectivity-aware navigation informed by LiDAR geometry and sky-visibility; (iii) handover analysis and prediction from per-satellite tracking; (iv) environment-aware adaptation under occlusions using point clouds and images; and (v) cross-layer experimentation with reproducible benchmarking resources. This restructuring reduces length while making the novelty and community relevance explicit: the artifacts support empirically grounded studies at the intersection of sensing, mobility, and networked systems that are central to *SenSys*.

Planned Revision 8:

Add Power Consumption Analysis: We will include descriptions of the platform's overall power consumption and operational endurance (battery life) during data collection missions within the existing system description sections.

Implementation:

We added a short statement to **Section 3.1 (Hardware Architecture)** summarizing the estimated power consumption and operational endurance. The revised text reports approximately 60–110 W for the wheeled base and 20–40 W for the Starlink Mini (≈ 15 W idle). It also notes that the system sustained stable operation for about two hours per deployment, reflecting measured endurance in real experiments. These values are derived from vendor specifications and observed field behavior, offering a practical reference for evaluating system feasibility.

The Starlink Robot: A Platform and Dataset for Mobile Satellite Communication

Abstract

The integration of satellite communication into mobile devices represents a paradigm shift in connectivity, yet the performance characteristics under motion and environmental occlusion remain poorly understood. We present the Starlink Robot, the first mobile robotic platform equipped with Starlink satellite internet, comprehensive sensor suite including upward-facing camera, LiDAR, and IMU, designed to systematically study satellite communication performance during movement. Our multi-modal dataset captures synchronized communication metrics, motion dynamics, sky visibility, and 3D environmental context across diverse scenarios including steady-state motion, variable speeds, and different occlusion conditions. This platform and dataset enable researchers to develop motion-aware communication protocols, predict connectivity disruptions, and optimize satellite communication for emerging mobile applications from smartphones to autonomous vehicles. [In this work, we use LEOviz for real-time data collection and visualization.](#) [The project is available at https://starlinkrobot.github.io.](https://starlinkrobot.github.io)

Keywords

Satellite Communication, Mobile Systems, Robot, Starlink

1 Introduction

The landscape of global connectivity is undergoing a fundamental transformation. SpaceX’s Starlink constellation has deployed over 5,000 satellites, delivering high-speed internet to previously unreachable locations [25]. This success has catalyzed a broader revolution: major technology companies including Apple, Samsung, and Google are racing to integrate satellite communication capabilities directly into consumer smartphones, with Apple’s Emergency SOS already saving lives in remote locations and Google partnering with Skylo for Android satellite messaging [5, 16].

Yet this promise faces a critical challenge. Current satellite internet deployments predominantly serve stationary users – homes, businesses, and fixed installations [6]. The Starlink Mini’s recent introduction has made portable satellite internet more accessible [25], but fundamental questions remain unanswered. How does motion affect satellite link quality? What happens when agricultural drones monitor vast farmlands beyond cellular coverage, or when emergency responders navigate disaster zones where terrestrial infrastructure has failed [4, 22]? These questions become urgent for applications where LTE simply cannot reach: maritime vessels tracking cargo across oceans, wildlife researchers following migrations in remote habitats, and autonomous vehicles traversing rural areas where cellular towers are economically unfeasible.

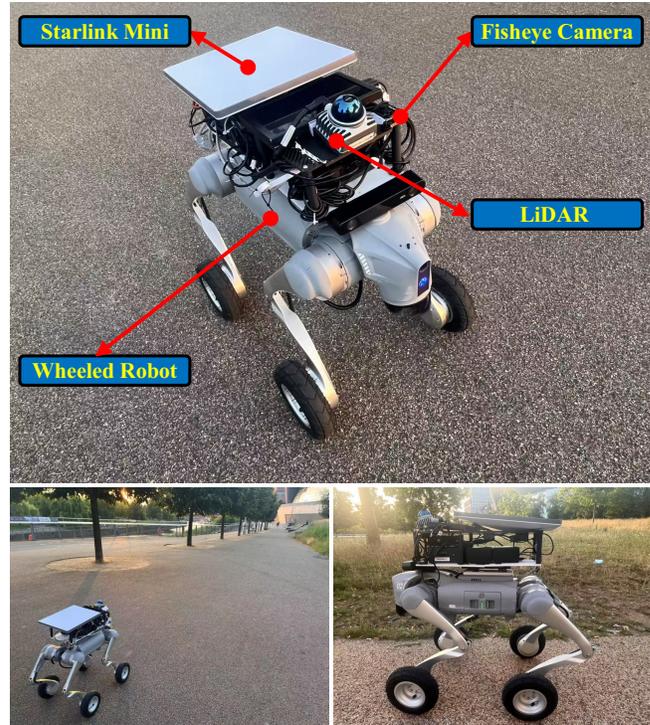


Figure 1. The Starlink Robot platform integrating a Unitree GO2 wheeled robot with Starlink Mini terminal, upward-facing fisheye camera, and Livox Mid-360 LiDAR for comprehensive mobile satellite communication research

The challenge extends beyond simple mobility. Satellite communication operates under fundamentally different constraints than terrestrial networks [4, 6, 8, 22]. A moving device must maintain connection with satellites traveling at 7.5 km/s while simultaneously dealing with local motion and environmental occlusions [4]. Trees, buildings, and even the device’s own orientation can disrupt the delicate link between Earth and space [4, 22]. Unlike terrestrial networks where signal paths remain relatively stable, satellite links must contend with both terrestrial motion and satellites racing overhead at 27,000 km/h, creating a uniquely dynamic communication environment [4, 6, 8, 22]. Understanding these dynamics requires more than theoretical models – it demands real-world data collected under controlled yet realistic conditions [4, 6].

To address this gap, we developed the Starlink Robot shown in Figure 1, a purpose-built **platform** that brings together mobile robotics and satellite communication. Our approach transforms a Unitree GO2 wheeled robot into a mobile laboratory, equipped with Starlink Mini for connectivity and a suite of sensors to capture the complete context of communication performance. The upward-facing fisheye camera observes sky visibility, the Livox Mid-360 LiDAR

maps the surrounding environment, and integrated IMUs track every movement. This comprehensive sensing enables us to correlate communication metrics with physical conditions, revealing how motion and occlusion influence satellite connectivity.

Our contribution extends beyond the platform itself. We present a **multi-modal dataset** that synchronizes Starlink performance metrics – including latency, upload and download throughput, and signal quality indicators – with high-frequency motion data and environmental observations. [Satellite tracking data is collected using LEOViz \[3, 30\], which provides real-time visualization of satellite positions and connection status.](#) This dataset captures diverse scenarios from steady locomotion to variable speeds, from open sky to heavily occluded urban environments. By releasing both our platform design and collected data, we provide the research community with tools to develop the next generation of mobile satellite communication systems. Our initial dataset contains 7 hours of synchronized multi-modal data collected across diverse urban environments in London, with ongoing data collection expanding the dataset. The current release includes over 25K RTT measurements, 630k LiDAR frames, and 378k fisheye images, covering open areas, tree-covered paths, and urban environments at varying movement speeds.

2 Related Works

The rapid deployment of LEO satellite constellations has sparked significant research interest in characterizing their performance. The Starlink academic community, particularly through the University of Victoria’s PanLab, has produced comprehensive studies of Starlink’s several static performance characteristics [3, 7, 9, 11, 14, 15, 17, 18, 20, 23, 24, 26–29, 31, 32]. Among these, LEOViz [3, 30] provides real-time visualization and tracking of Starlink satellites, displaying satellite positions, elevation angles, and connection status. In our work, we utilize LEOViz as our data collection and visualization tool, running it alongside our robotic platform to record satellite tracking information during mobile experiments. The satellite data captured by LEOViz enables us to analyze satellite communication performance during movement. Kassem et al. analyzed throughput variations across geographic locations, revealing how latitude affects connection quality due to satellite density differences [12]. Muhammad et al. investigated weather impacts, demonstrating that rain fade affects Starlink less severely than traditional geostationary satellites due to shorter signal paths [21]. These foundational studies establish baseline performance metrics but explicitly acknowledge the limitation of stationary measurements.

Recent work has begun exploring mobility scenarios, though primarily in constrained settings. Laniewski et al. conducted preliminary tests with Starlink terminals in vehicles, reporting increased latency variance during highway driving [13]. However, their study lacked synchronized motion data and environmental context, making it difficult to isolate causative

factors, and the dataset is not open-sourced. SpaceX Maritime [2] deployments documented by SpaceX show promising performance on ships, but the relatively stable motion and unobstructed ocean views present a best-case scenario that doesn’t translate to terrestrial mobile applications. The fundamental challenge remains: no existing work provides the fine-grained, multi-modal data necessary to understand how specific motion patterns and environmental conditions affect satellite communication.

The robotics community has long recognized the value of mobile platforms for wireless communication research. The CRAWDAD repository [1] contains numerous datasets from robot-mounted WiFi experiments, demonstrating how controlled mobility can reveal network behavior patterns invisible in static deployments. More recently, researchers have employed drones to map 5G coverage, taking advantage of three-dimensional mobility to characterize cellular networks [19]. Yet these efforts remain confined to terrestrial communication systems [10]. The unique challenges of satellite communication – including the need for precise sky visibility, the impact of antenna orientation, and the effects of Doppler shift from dual mobility – require purpose-built platforms and measurement methodologies. Our work bridges this gap by adapting mobile robotics techniques specifically for satellite communication research, creating a reproducible platform that others can build upon.

Overall, our work proposes the first dedicated platform for *mobile satellite communication* research, providing the tools and data necessary to understand this emerging communication paradigm.

3 System Design

The Starlink Robot platform integrates three core subsystems to enable comprehensive mobile satellite communication research. As illustrated in Figure 2, the Mobile Platform subsystem combines the Unitree GO2 robot base with the Starlink Mini terminal, providing controlled mobility with precise velocity and position tracking. The Sensor Suite subsystem synchronizes multiple data streams: the Livox Mid-360 LiDAR captures 3D environmental geometry, the upward fisheye camera monitors sky visibility for obstruction detection, while IMU and GPS units track motion dynamics and global positioning. The Data Processing subsystem handles real-time synchronization of these heterogeneous data sources, logging both raw sensor data and processed metrics for offline analysis. This architecture enables researchers to correlate communication performance with environmental and motion contexts at millisecond precision.

3.1 Hardware Architecture

The hardware platform, shown in Figure 1, integrates mobility, communication, and sensing capabilities through a set of integrated components:

Mobile Base: The Unitree Go2 wheeled version provides the foundation with a 15 kg payload capacity and differential drive system. The wheeled configuration provides smooth,

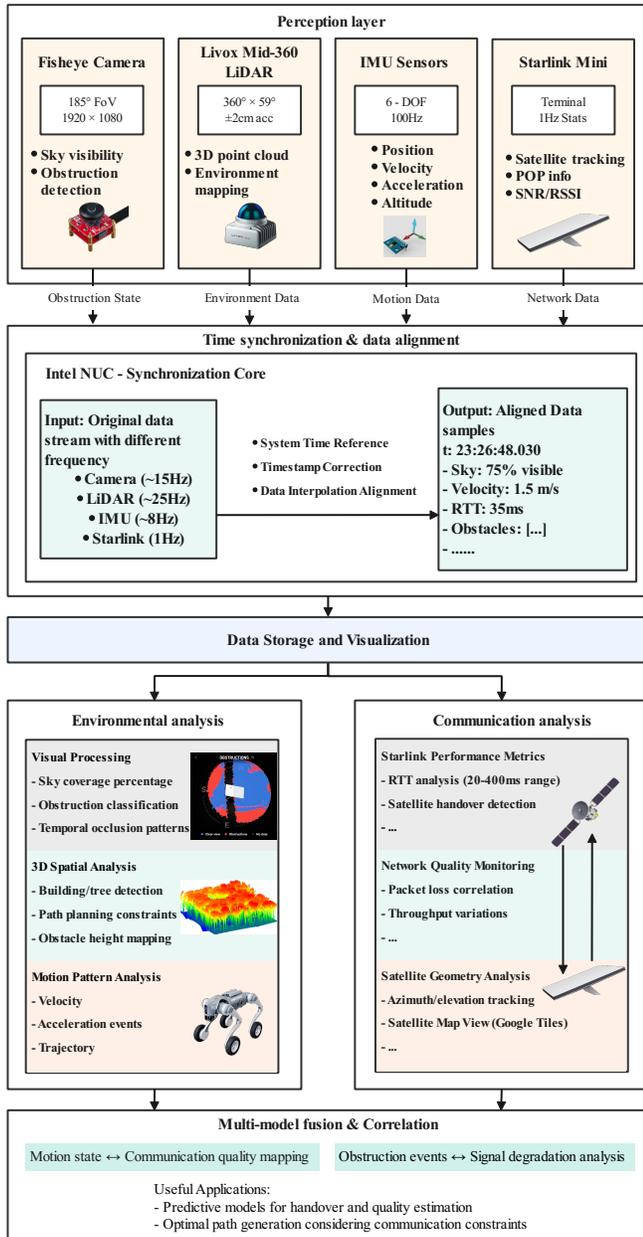


Figure 2. System architecture of the Starlink Robot platform showing multi-modal sensor integration, data synchronization pipeline, and analysis framework for correlating communication performance with environmental and motion context.

continuous movement that helps isolate communication variations from motion artifacts. The platform supports precise velocity control from 0.1 m/s to 2.0 m/s, covering typical pedestrian movement speeds.

Communication System: The Starlink Mini terminal is mounted on a 3D-printed support structure that replaces the earlier aluminum frame. The mount maintains a stable upward orientation and reduces vibration transmission from the base. The terminal connects to the onboard Intel NUC via Ethernet and receives power through a DC-DC converter that steps down the robot’s 24 V supply to Starlink’s 12 V

input. In LEOViz, the Starlink gRPC interface is accessed through a local Python client for periodic telemetry queries.

Sensing Configuration: The sensing suite captures the environmental and motion context required for link analysis. It includes a Livox Mid-360 LiDAR (360° field of view at 25 Hz, 0.05 m range accuracy) and an upward-facing fisheye camera (185° FoV at 15 Hz) for sky-visibility monitoring. No dedicated IMU or GPS module is installed. Motion and localization data are instead obtained from the robot’s internal SLAM estimator and the localization output of the built-in Starlink terminal.

Computing Platform: An Intel NUC running Ubuntu 18.04 with ROS Noetic serves as the central node, handling sensor synchronization, data logging, and real-time processing. All incoming data—including Starlink telemetry, SLAM motion traces, LiDAR frames, and camera images—are timestamped using the NUC’s system clock as a unified time source, providing sub-millisecond alignment across modalities.

Power Consumption: During normal operation, the platform draws approximately 60–110 W for the mobile base (low to moderate speeds) and 20–40 W for the Starlink Mini terminal (about 15 W when idle). In field experiments, the system operated continuously and stably for about two hours per deployment without performance degradation.

3.2 Software Architecture

Mobile satellite communication research demands precise temporal alignment across diverse data streams to establish causal relationships between motion, environment, and performance. A position change of just one meter or an obstruction lasting mere seconds can dramatically impact satellite connectivity. Our ROS-based framework therefore treats time synchronization as a fundamental design principle. Each sensor node implements hardware triggering where available (LiDAR, camera) and kernel-level timestamping for software-triggered sensors (network metrics). A dedicated synchronization node correlates these timestamps against GPS time when available, achieving sub-millisecond alignment accuracy essential for correlating transient communication events with their physical causes.

The Starlink data collection presents unique challenges as the terminal doesn’t expose a direct API. We employ a multi-layered approach: for satellite tracking and constellation data, we use LEOViz [3, 30], which handles the parsing of Starlink’s gRPC status interface and provides 1Hz updates on satellite positions, azimuth/elevation angles, signal quality, and connection status. LEOViz visualizes this data in real-time and we record its output during our experiments.

The diverse sensors generate data at different rates that must be efficiently stored and synchronized. During experiments, the ROS framework saves LiDAR point clouds, camera images, and IMU measurements directly to bag files on the onboard computer’s SSD. Network measurements from the Starlink terminal and our active probing tools are logged separately as CSV files with timestamps. After each session,

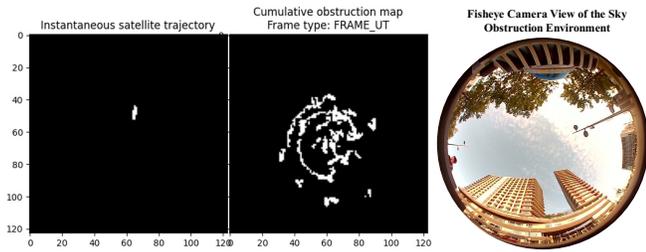


Figure 3. Starlink terminal’s obstruction detection output (left) that is visualized by LEOViz [3, 30], and Dual-view obstruction analysis showing fisheye camera sky visibility (right), demonstrating real-time obstruction mapping capabilities.

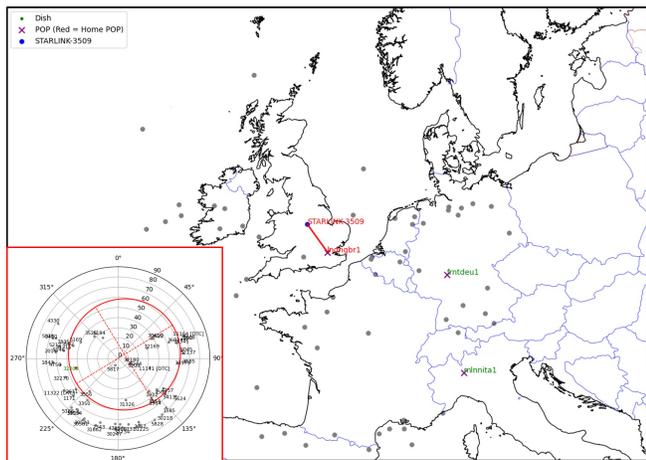


Figure 4. Satellite constellation visualization using LEOViz [3, 30], displaying active Starlink satellites’ positions, elevation angles, and connection status relative to the robot’s location during data collection.

we process these multiple data sources: our synchronization software reads the timestamps from each file, aligns them using the GPS clock as reference, and combines everything into a single HDF5 file. This unified format allows researchers to access all sensor data and communication metrics with consistent timestamps without dealing with multiple file formats.

4 Dataset Description

Our dataset represents 7 hours of synchronized multi-modal sensor data from the Starlink Robot platform, comprising approximately 120GB collected across diverse environmental categories in London: open spaces (40%), tree-covered areas (35%), and urban environments (25%). With 98.5% data completeness and sub-millisecond synchronization accuracy, this dataset provides the foundation for developing robust mobile satellite communication systems.

Obstruction Detection Data. As shown in Figure 3, we provide dual obstruction detection: fisheye camera images (1920×1080, 15Hz, 185-degree FOV) for sky visibility analysis, and Starlink terminal’s internal obstruction detection output. Both streams are time-synchronized for comparison between visual obstruction and the terminal’s algorithms.

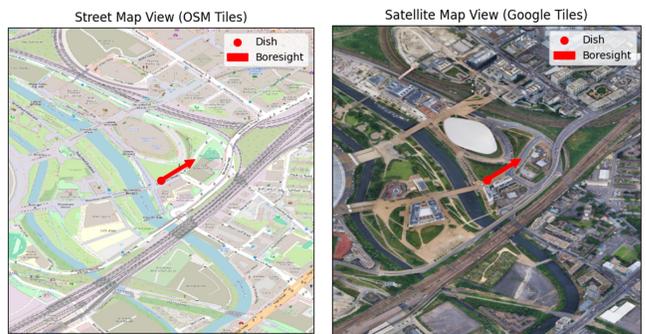


Figure 5. Google map view of the localization utilized LEOViz [3, 30].



Figure 6. LiDAR-based 3D point cloud visualization capturing environmental geometry around the robot, enabling precise obstruction detection.

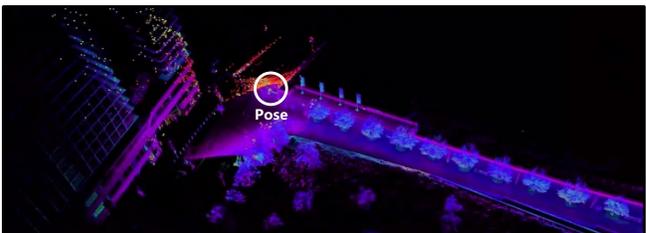


Figure 7. Robot pose and motion data indicating position, velocity, orientation, and trajectory information synchronized with communication performance metrics

Satellite Tracking Information. Figure 4 illustrates real-time satellite tracking data collected at 1Hz. For each visible satellite, we record azimuth, elevation, signal strength, and connection status, enabling analysis of handover patterns and satellite selection behavior during mobile operation.

Location and Path Data. GPS positioning at 1Hz provides global coordinates of the robot’s trajectory (Figure 5). Our experimental paths cover diverse urban environments with varying obstruction characteristics, supplemented by wheel odometry at 8Hz for improved position accuracy.

3D Environmental Mapping. The Livox Mid-360 LiDAR captures 360-degree point clouds at 25Hz with 0.05m accuracy up to 40 meters (Figure 6), enabling 3D reconstruction and correlation with communication performance.

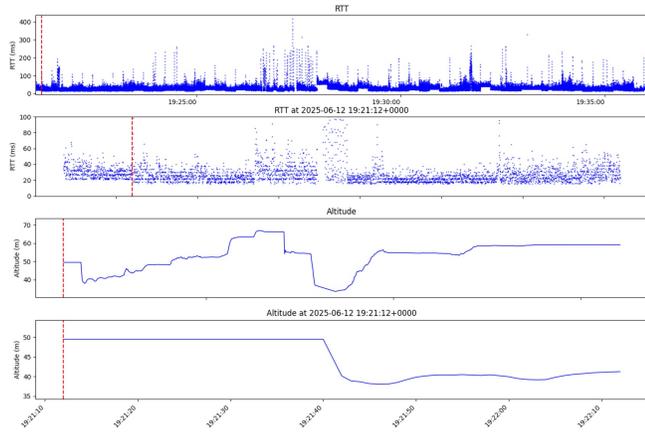


Figure 8. Multi-metric Starlink communication performance indicating RTT variations and altitude profiles during mobile operation.

Robot Motion and Pose Data. Figure 7 presents comprehensive motion data from IMU (8Hz) and wheel encoders, providing complete 6-DOF pose estimation including position, orientation, velocity, and acceleration to capture vibrations, turns, and speed variations.

Communication Performance Metrics. The core of our dataset is the Starlink communication measurements shown in Figure 8. We collect with LEOViz: (1) Terminal-reported statistics at 1 Hz including downlink/uplink throughput, RTT, SNR, and obstruction state; (2) Active network measurements with ICMP probes at 10 Hz to multiple servers; (3) TCP/UDP throughput tests every 30 seconds. All communication data is timestamped and synchronized with sensor data.

Data Format and Organization. The dataset follows a unified structure designed for easy parsing and synchronization. Raw sensor data are stored as ROS bag files, which contain LiDAR point clouds, fisheye camera images, IMU readings, and GPS information. Processed communication metrics and satellite tracking logs are exported as CSV files, while all synchronized multi-modal data are aggregated into HDF5 format for efficient analysis. Comprehensive documentation describing the dataset directory hierarchy, file naming conventions, and data schema (ROS bags, CSVs, and HDF5) is available on the companion site of <https://starlinkrobot.github.io>. The site also provides well-commented sample scripts for parsing, aligning, and visualizing the data, demonstrating how to reproduce major figures in the paper and extend the dataset for new experiments.

5 Preliminary Findings

To demonstrate our platform’s utility, we present two case studies examining critical factors in mobile satellite communication. These analyses, conducted in the London Olympic Sports Center area, reveal how movement velocity and environmental transitions affect Starlink performance.

5.1 Impact of Movement Velocity

Experimental Setup: We conducted controlled velocity experiments along a 2km loop through open campus areas,

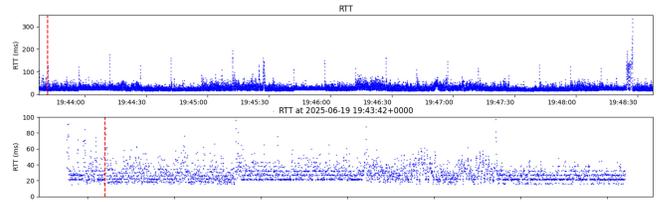


Figure 9. RTT performance during low-speed movement showing communication stability and handover patterns while maintaining slow velocity.

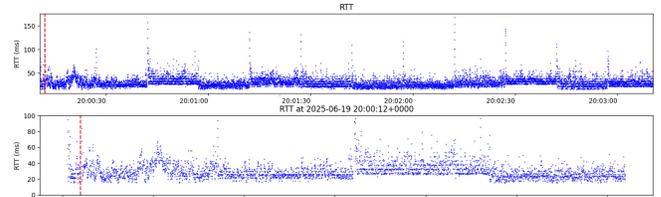


Figure 10. RTT performance during fast-speed movement (2.0 m/s) demonstrating minimal velocity impact on communication quality with slight increase in latency variance.

maintaining consistent environmental conditions while varying movement speed. The robot completed multiple runs at 0.8 m/s (walking speed) and 2.0 m/s (jogging pace), with 5-minute stationary periods between runs for baseline comparison.

Results and Analysis: Figures 9 and 10 show RTT measurements remain remarkably stable at both velocities, concentrated in the 35–45 ms range, with an average of 40.2 ms (± 2.3 ms, 95% CI) at walking speed and 41.8 ms (± 2.7 ms, 95% CI) at jogging speed. The characteristic 15-second satellite handovers appear as step changes regardless of ground velocity. While faster movement introduces marginally higher variance (occasional spikes to 60-70ms vs. consistent 35-45ms at slow speeds), these variations remain within acceptable bounds. This minimal degradation demonstrates Starlink’s phased array technology effectively compensates for ground motion through electronic beam steering, contrasting sharply with terrestrial networks where speed typically correlates with degraded performance.

5.2 Impact of Environmental Obstructions

Mobile devices must continuously adapt to changing environmental conditions. Our data captures performance across representative urban environments, demonstrating the profound influence of environmental dynamics on satellite communication.

Open Environment Performance: In unobstructed areas (Figure 11), Starlink exhibits fundamental LEO satellite characteristics. Figure 12 shows periodic RTT fluctuations between 20–40 ms, with a mean of 31.5 ms (± 3.1 ms, 95% CI) in open areas. In contrast, under tree-covered paths (Figure 15), RTT exhibits frequent spikes reaching 40–100 ms, with a mean of 56.4 ms (± 6.2 ms, 95% CI). These patterns remain highly regular, providing a performance baseline for mobile applications.



Figure 11. Environmental context and the robot running scenario in open area showing robot deployment location, surrounding infrastructure, and clear sky conditions from multiple viewpoints.

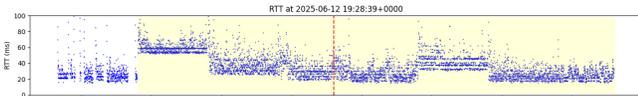


Figure 12. Extended RTT measurements in open environment demonstrating periodic satellite handover patterns and baseline performance characteristics without environmental obstructions.

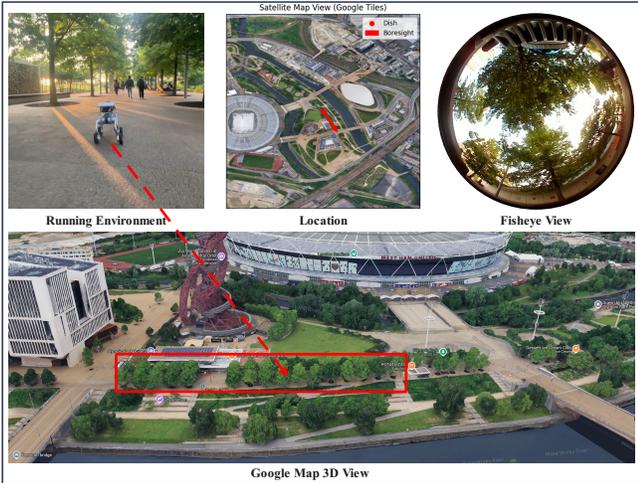


Figure 13. Environmental context and the robot running scenario in tree-covered area showing robot navigation through foliage-dense paths with limited sky visibility.

Obstructed Environment Challenges: Tree-lined streets (Figure 13) create dramatically different conditions. The LiDAR visualization (Figure 14) reveals how dense canopy limits sky visibility to narrow corridors. This constraint fundamentally alters communication dynamics, as shown in Figure 15: RTT exhibits severe instability with frequent spikes reaching 40-100ms. These degradations result from reduced satellite selection options, intermittent signal fluctuations through canopy gaps, and continuous parameter adjustments by obstruction detection algorithms.

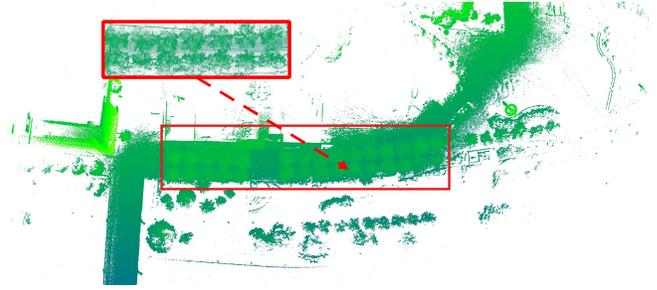


Figure 14. LiDAR point cloud visualization of tree-covered environment illustrating canopy density and potential signal obstruction patterns affecting satellite communication.

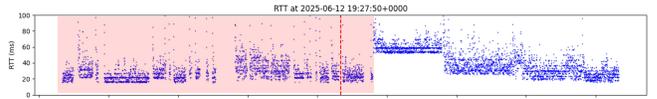


Figure 15. Communication performance in tree-covered environment demonstrating increased RTT instability and frequent spikes due to limited satellite visibility.

Environmental Transitions: The most revealing insights emerge during transitions. When moving from tree cover to open areas, RTT stabilizes within seconds with baseline shifts of 10-20ms and variance reductions exceeding 50%. Unlike terrestrial networks that benefit from multipath propagation, satellite links exhibit binary behavior: sufficient sky visibility enables stable connection, while obstructions cause severe degradation. This distinction makes path planning crucial for mobile satellite applications, as even brief passages under obstructions can disrupt service entirely.

6 Research Opportunities and Conclusion

Our deployable platform and synchronized multi-modal dataset support several concrete research directions in mobile sensing and networked systems. For example, **first, motion-aware networking:** millisecond-aligned RTT measurements with SLAM-derived motion traces can be used to analyze how velocity, acceleration, and orientation correlate with link quality, and to evaluate adaptive transport and scheduling under mobility. **Second, connectivity-aware navigation:** LiDAR geometry and fisheye sky-visibility enable path planning that balances travel distance with expected link continuity, which is relevant to robots and vehicles operating beyond reliable terrestrial coverage. **Third, handover analysis and prediction:** per-satellite azimuth/elevation and connection status provide inputs for modeling handover timing and selection under motion. **Finally, environment-aware adaptation:** point clouds and images capturing canopy density and urban morphology allow policies that adjust redundancy, or probing during occlusions.

Our platform and dataset address this research gap by providing synchronized, multi-modal data to correlate communication metrics with motion and environmental context. Open-sourcing these resources provides ground truth for developing adaptive protocols and supports community efforts toward seamless network integration.

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The Starlink Robot: A Platform and Dataset for Mobile Satellite Communication

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Abstract

The integration of satellite communication into mobile devices represents a paradigm shift in connectivity, yet the performance characteristics under motion and environmental occlusion remain poorly understood. We present the Starlink Robot, the first mobile robotic platform equipped with Starlink satellite internet, comprehensive sensor suite including upward-facing camera, LiDAR, and IMU, designed to systematically study satellite communication performance during movement. Our multi-modal dataset captures synchronized communication metrics, motion dynamics, sky visibility, and 3D environmental context across diverse scenarios including steady-state motion, variable speeds, and different occlusion conditions. This platform and dataset enable researchers to develop motion-aware communication protocols, predict connectivity disruptions, and optimize satellite communication for emerging mobile applications from smartphones to autonomous vehicles. In this work, we use *LEOViz* for real-time data collection and visualization. The project is available at <https://starlinkrobot.github.io>.

Keywords

Satellite Communication, Mobile Systems, Robot, Starlink

1 Introduction

The landscape of global connectivity is undergoing a fundamental transformation. SpaceX’s Starlink constellation has deployed over 5,000 satellites, delivering high-speed internet to previously unreachable locations [25]. This success has catalyzed a broader revolution: major technology companies including Apple, Samsung, and Google are racing to integrate satellite communication capabilities directly into consumer smartphones, with Apple’s Emergency SOS already saving lives in remote locations and Google partnering with Skylo for Android satellite messaging [5, 16].

Yet this promise faces a critical challenge. Current satellite internet deployments predominantly serve stationary users – homes, businesses, and fixed installations [6]. The Starlink Mini’s recent introduction has made portable satellite internet more accessible [25], but fundamental questions remain unanswered. How does motion affect satellite link quality? What happens when agricultural drones monitor vast farmlands beyond cellular coverage, or when emergency responders navigate disaster zones where terrestrial infrastructure has failed [4, 22]? These questions become urgent

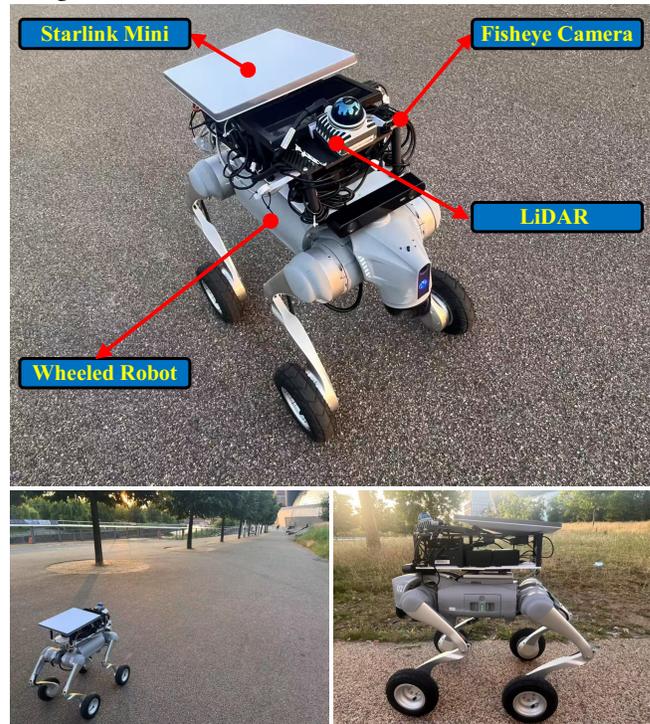


Figure 1. The Starlink Robot platform integrating a Unitree GO2 wheeled robot with Starlink Mini terminal, upward-facing fisheye camera, and Livox Mid-360 LiDAR for comprehensive mobile satellite communication research

for applications where LTE simply cannot reach: maritime vessels tracking cargo across oceans, wildlife researchers following migrations in remote habitats, and autonomous vehicles traversing rural areas where cellular towers are economically unfeasible.

The challenge extends beyond simple mobility. Satellite communication operates under fundamentally different constraints than terrestrial networks [4, 6, 8, 22]. A moving device must maintain connection with satellites traveling at 7.5 km/s while simultaneously dealing with local motion and environmental occlusions [4]. Trees, buildings, and even the device’s own orientation can disrupt the delicate link between Earth and space [4, 22]. Unlike terrestrial networks where signal paths remain relatively stable, satellite links must contend with both terrestrial motion and satellites racing overhead at 27,000 km/h, creating a uniquely dynamic communication environment [4, 6, 8, 22]. Understanding these dynamics requires more than theoretical models – it

demands real-world data collected under controlled yet realistic conditions [4, 6].

To address this gap, we developed the Starlink Robot shown in Figure 1, a purpose-built **platform** that brings together mobile robotics and satellite communication. Our approach transforms a Unitree GO2 wheeled robot into a mobile laboratory, equipped with Starlink Mini for connectivity and a suite of sensors to capture the complete context of communication performance. The upward-facing fisheye camera observes sky visibility, the Livox Mid-360 LiDAR maps the surrounding environment, and integrated IMUs track every movement. This comprehensive sensing enables us to correlate communication metrics with physical conditions, revealing how motion and occlusion influence satellite connectivity.

Our contribution extends beyond the platform itself. We present a **multi-modal dataset** that synchronizes Starlink performance metrics – including latency, upload and download throughput, and signal quality indicators – with high-frequency motion data and environmental observations. Satellite tracking data is collected using LEOViz [3, 30], which provides real-time visualization of satellite positions and connection status. This dataset captures diverse scenarios from steady locomotion to variable speeds, from open sky to heavily occluded urban environments. By releasing both our platform design and collected data, we provide the research community with tools to develop the next generation of mobile satellite communication systems. Our initial dataset contains 7 hours of synchronized multi-modal data collected across diverse urban environments in London, with ongoing data collection expanding the dataset. The current release includes over 25K RTT measurements, 630k LiDAR frames, and 378k fisheye images, covering open areas, tree-covered paths, and urban environments at varying movement speeds.

2 Related Works

The rapid deployment of LEO satellite constellations has sparked significant research interest in characterizing their performance. The Starlink academic community, particularly through the University of Victoria’s PanLab, has produced comprehensive studies of Starlink’s several static performance characteristics [3, 7, 9, 11, 14, 15, 17, 18, 20, 23, 24, 26–29, 31, 32]. Among these, LEOViz [3, 30] provides real-time visualization and tracking of Starlink satellites, displaying satellite positions, elevation angles, and connection status. In our work, we utilize LEOViz as our data collection and visualization tool, running it alongside our robotic platform to record satellite tracking information during mobile experiments. The satellite data captured by LEOViz enables us to analyze satellite communication performance during movement. Kassem et al. analyzed throughput variations across geographic locations, revealing how latitude affects connection quality due to satellite density differences [12]. Muhammad et al. investigated weather impacts, demonstrating that

rain fade affects Starlink less severely than traditional geostationary satellites due to shorter signal paths [21]. These foundational studies establish baseline performance metrics but explicitly acknowledge the limitation of stationary measurements.

Recent work has begun exploring mobility scenarios, though primarily in constrained settings. Laniewski et al. conducted preliminary tests with Starlink terminals in vehicles, reporting increased latency variance during highway driving [13]. However, their study lacked synchronized motion data and environmental context, making it difficult to isolate causative factors, and the dataset is not open-sourced. SpaceX Maritime [2] deployments documented by SpaceX show promising performance on ships, but the relatively stable motion and unobstructed ocean views present a best-case scenario that doesn’t translate to terrestrial mobile applications. The fundamental challenge remains: no existing work provides the fine-grained, multi-modal data necessary to understand how specific motion patterns and environmental conditions affect satellite communication.

The robotics community has long recognized the value of mobile platforms for wireless communication research. The CRAWDED repository [1] contains numerous datasets from robot-mounted WiFi experiments, demonstrating how controlled mobility can reveal network behavior patterns invisible in static deployments. More recently, researchers have employed drones to map 5G coverage, taking advantage of three-dimensional mobility to characterize cellular networks [19]. Yet these efforts remain confined to terrestrial communication systems [10]. The unique challenges of satellite communication – including the need for precise sky visibility, the impact of antenna orientation, and the effects of Doppler shift from dual mobility – require purpose-built platforms and measurement methodologies. Our work bridges this gap by adapting mobile robotics techniques specifically for satellite communication research, creating a reproducible platform that others can build upon.

Overall, our work proposes the first dedicated platform for *mobile satellite communication* research, providing the tools and data necessary to understand this emerging communication paradigm.

3 System Design

The Starlink Robot platform integrates three core subsystems to enable comprehensive mobile satellite communication research. As illustrated in Figure 2, the Mobile Platform subsystem combines the Unitree GO2 robot base with the Starlink Mini terminal, providing controlled mobility with precise velocity and position tracking. The Sensor Suite subsystem synchronizes multiple data streams: the Livox Mid-360 LiDAR captures 3D environmental geometry, the upward fisheye camera monitors sky visibility for obstruction detection, while IMU and GPS units track motion dynamics and global positioning. The Data Processing subsystem handles real-time synchronization of these heterogeneous data

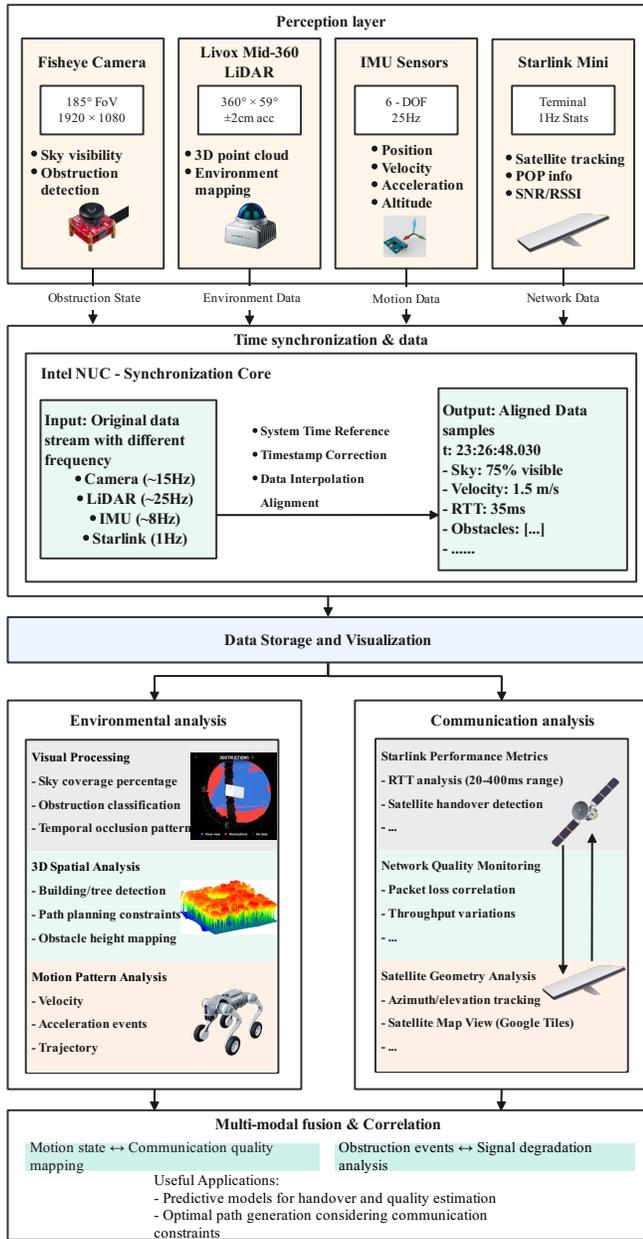


Figure 2. System architecture of the Starlink Robot platform showing multi-modal sensor integration, data synchronization pipeline, and analysis framework for correlating communication performance with environmental and motion context.

sources, logging both raw sensor data and processed metrics for offline analysis. This architecture enables researchers to correlate communication performance with environmental and motion contexts at millisecond precision.

3.1 Hardware Architecture

The hardware platform, shown in Figure 1, integrates mobility, communication, and sensing capabilities through a set of integrated components:

Mobile Base: The Unitree Go2 wheeled version provides the foundation with a 15 kg payload capacity and differential drive system. The wheeled configuration provides smooth,

continuous movement that helps isolate communication variations from motion artifacts. The platform supports precise velocity control from 0.1 m/s to 2.0 m/s, covering typical pedestrian movement speeds.

Communication System: The Starlink Mini terminal is mounted on a 3D-printed support structure that replaces the earlier aluminum frame. The mount maintains a stable upward orientation and reduces vibration transmission from the base. The terminal connects to the onboard Intel NUC via Ethernet and receives power through a DC-DC converter that steps down the robot’s 24 V supply to Starlink’s 12 V input. In LEOViz, the Starlink gRPC interface is accessed through a local Python client for periodic telemetry queries.

Sensing Configuration: The sensing suite captures the environmental and motion context required for link analysis. It includes a Livox Mid-360 LiDAR (360° field of view at 25 Hz, 0.05 m range accuracy) and an upward-facing fisheye camera (185° FoV at 15 Hz) for sky-visibility monitoring. No dedicated IMU or GPS module is installed. Motion and localization data are instead obtained from the robot’s internal SLAM estimator and the localization output of the built-in Starlink terminal.

Computing Platform: An Intel NUC running Ubuntu 20.04 with ROS Noetic serves as the central node, handling sensor synchronization, data logging, and real-time processing. All incoming data—including Starlink telemetry, SLAM motion traces, LiDAR frames, and camera images—are timestamped using the NUC’s system clock as a unified time source, providing sub-millisecond alignment across modalities.

Power Consumption: During normal operation, the platform draws approximately 60–110 W for the mobile base (low to moderate speeds) and 20–40 W for the Starlink Mini terminal (about 15 W when idle). In field experiments, the system operated continuously and stably for about two hours per deployment without performance degradation.

3.2 Software Architecture

Mobile satellite communication research demands precise temporal alignment across diverse data streams to establish causal relationships between motion, environment, and performance. A position change of just one meter or an obstruction lasting mere seconds can dramatically impact satellite connectivity. Our ROS-based framework therefore treats time synchronization as a fundamental design principle. Each sensor node implements hardware triggering where available (LiDAR, camera) and kernel-level timestamping for software-triggered sensors (network metrics). A dedicated synchronization node correlates these timestamps against GPS time when available, achieving sub-millisecond alignment accuracy essential for correlating transient communication events with their physical causes.

The Starlink data collection presents unique challenges as the terminal doesn’t expose a direct API. We employ a multi-layered approach: for satellite tracking and constellation data, we use LEOViz [3, 30], which handles the parsing of

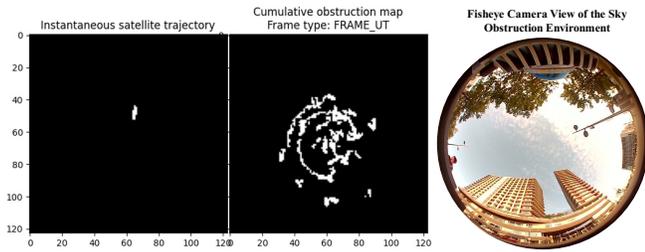


Figure 3. Starlink terminal’s obstruction detection output (left) that is visualized by LEOViz [3, 30], and Dual-view obstruction analysis showing fisheye camera sky visibility (right), demonstrating real-time obstruction mapping capabilities.

Starlink’s gRPC status interface and provides 1Hz updates on satellite positions, azimuth/elevation angles, signal quality, and connection status. LEOViz visualizes this data in real-time and we record its output during our experiments.

The diverse sensors generate data at different rates that must be efficiently stored and synchronized. During experiments, the ROS framework saves LiDAR point clouds, camera images, and IMU measurements directly to bag files on the onboard computer’s SSD. Network measurements from the Starlink terminal and our active probing tools are logged separately as CSV files with timestamps. After each session, we process these multiple data sources: our synchronization software reads the timestamps from each file, aligns them using the GPS clock as reference, and combines everything into a single HDF5 file. This unified format allows researchers to access all sensor data and communication metrics with consistent timestamps without dealing with multiple file formats.

4 Dataset Description

Our dataset represents 7 hours of synchronized multi-modal sensor data from the Starlink Robot platform, comprising approximately 120GB collected across diverse environmental categories in London: open spaces (40%), tree-covered areas (35%), and urban environments (25%). With 98.5% data completeness and sub-millisecond synchronization accuracy, this dataset provides the foundation for developing robust mobile satellite communication systems.

Obstruction Detection Data. As shown in Figure 3, we provide dual obstruction detection: fisheye camera images (1920×1080, 15Hz, 185-degree FOV) for sky visibility analysis, and Starlink terminal’s internal obstruction detection output. Both streams are time-synchronized for comparison between visual obstruction and the terminal’s algorithms.

Satellite Tracking Information. Figure 4 illustrates real-time satellite tracking data collected at 1Hz. For each visible satellite, we record azimuth, elevation, signal strength, and connection status, enabling analysis of handover patterns and satellite selection behavior during mobile operation.

Location and Path Data. GPS positioning at 1Hz provides global coordinates of the robot’s trajectory (Figure 5). Our experimental paths cover diverse urban environments

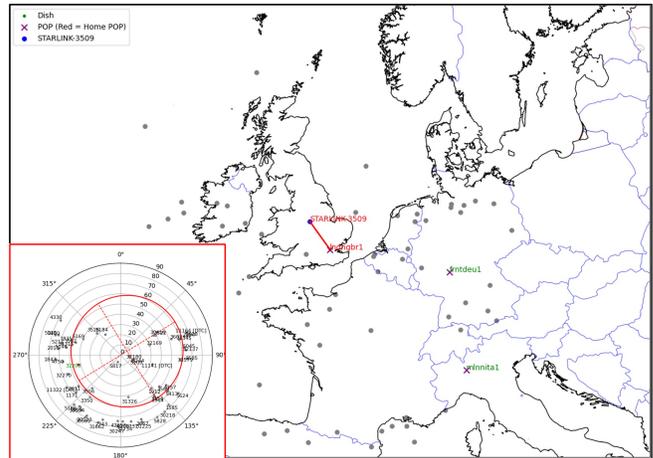


Figure 4. Satellite constellation visualization using LEOViz [3, 30], displaying active Starlink satellites’ positions, elevation angles, and connection status relative to the robot’s location during data collection.

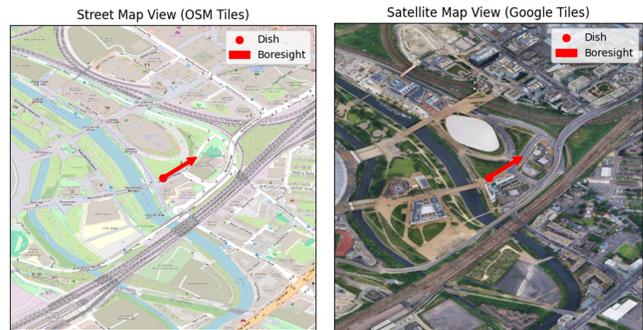


Figure 5. Google map view of the localization utilized LEOViz [3, 30].



Figure 6. LiDAR-based 3D point cloud visualization capturing environmental geometry around the robot, enabling precise obstruction detection.

with varying obstruction characteristics, supplemented by wheel odometry at 8Hz for improved position accuracy.

3D Environmental Mapping. The Livox Mid-360 LiDAR captures 360-degree point clouds at 25Hz with 0.05m accuracy up to 40 meters (Figure 6), enabling 3D reconstruction and correlation with communication performance.

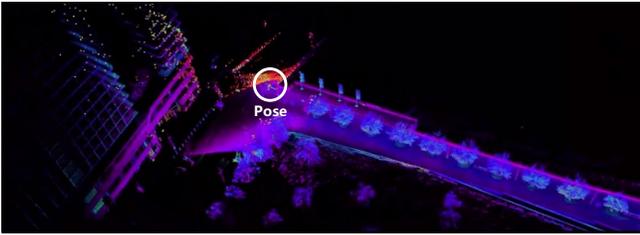


Figure 7. Robot pose and motion data indicating position, velocity, orientation, and trajectory information synchronized with communication performance metrics

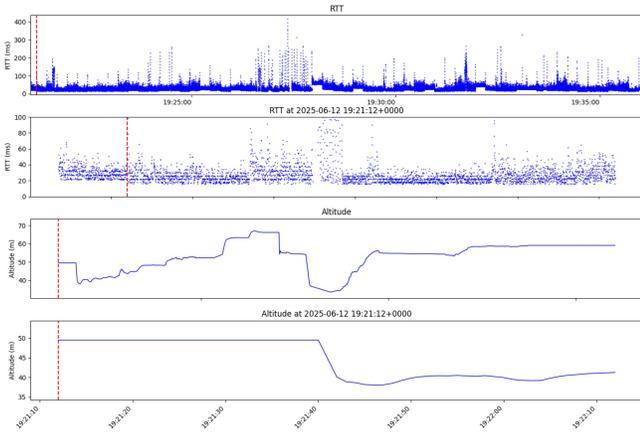


Figure 8. Multi-metric Starlink communication performance indicating RTT variations and altitude profiles during mobile operation.

Robot Motion and Pose Data. Figure 7 presents comprehensive motion data from IMU (8Hz) and wheel encoders, providing complete 6-DOF pose estimation including position, orientation, velocity, and acceleration to capture vibrations, turns, and speed variations.

Communication Performance Metrics. The core of our dataset is the Starlink communication measurements shown in Figure 8. We collect with LEOviz: (1) Terminal-reported statistics at 1 Hz including downlink/uplink throughput, RTT, SNR, and obstruction state; (2) Active network measurements with ICMP probes at 10 Hz to multiple servers; (3) TCP/UDP throughput tests every 30 seconds. All communication data is timestamped and synchronized with sensor data.

Data Format and Organization. The dataset follows a unified structure designed for easy parsing and synchronization. Raw sensor data are stored as ROS bag files, which contain LiDAR point clouds, fisheye camera images, IMU readings, and GPS information. Processed communication metrics and satellite tracking logs are exported as CSV files, while all synchronized multi-modal data are aggregated into HDF5 format for efficient analysis. Comprehensive documentation describing the dataset directory hierarchy, file naming conventions, and data schema (ROS bags, CSVs, and HDF5) is available on the companion site of <https://starlinkrobot.github.io>. The site also provides well-commented sample scripts for parsing, aligning, and visualizing the data, demonstrating how to reproduce major figures in the paper and extend the dataset for new experiments.

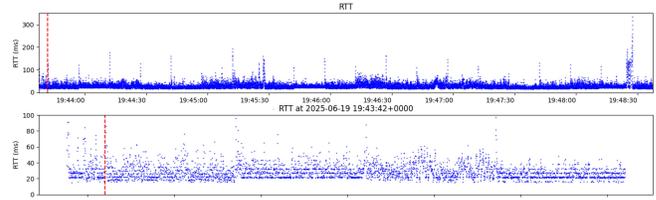


Figure 9. RTT performance during low-speed movement showing communication stability and handover patterns while maintaining slow velocity.

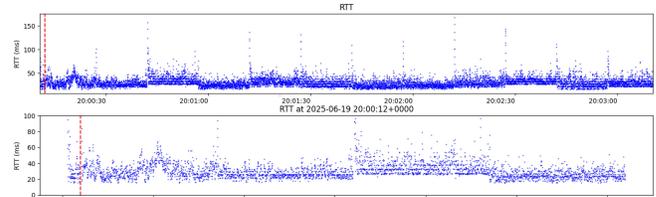


Figure 10. RTT performance during fast-speed movement (2.0 m/s) demonstrating minimal velocity impact on communication quality with slight increase in latency variance.

5 Preliminary Findings

To demonstrate our platform’s utility, we present two case studies examining critical factors in mobile satellite communication. These analyses, conducted in the London Olympic Sports Center area, reveal how movement velocity and environmental transitions affect Starlink performance.

5.1 Impact of Movement Velocity

Experimental Setup: We conducted controlled velocity experiments along a 2km loop through open campus areas, maintaining consistent environmental conditions while varying movement speed. The robot completed multiple runs at 0.8 m/s (walking speed) and 2.0 m/s (jogging pace), with 5-minute stationary periods between runs for baseline comparison.

Results and Analysis: Figures 9 and 10 show RTT measurements remain remarkably stable at both velocities, concentrated in the 35–45 ms range, with an average of 40.2 ms (± 2.3 ms, 95% CI) at walking speed and 41.8 ms (± 2.7 ms, 95% CI) at jogging speed. The characteristic 15-second satellite handovers appear as step changes regardless of ground velocity. While faster movement introduces marginally higher variance (occasional spikes to 60-70ms vs. consistent 35-45ms at slow speeds), these variations remain within acceptable bounds. This minimal degradation demonstrates Starlink’s phased array technology effectively compensates for ground motion through electronic beam steering, contrasting sharply with terrestrial networks where speed typically correlates with degraded performance.

5.2 Impact of Environmental Obstructions

Mobile devices must continuously adapt to changing environmental conditions. Our data captures performance across representative urban environments, demonstrating the profound influence of environmental dynamics on satellite communication.



Figure 11. Environmental context and the robot running scenario in open area showing robot deployment location, surrounding infrastructure, and clear sky conditions from multiple viewpoints.

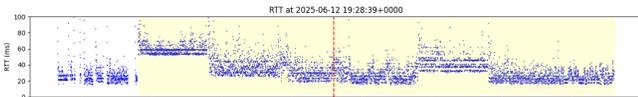


Figure 12. Extended RTT measurements in open environment demonstrating periodic satellite handover patterns and baseline performance characteristics without environmental obstructions.

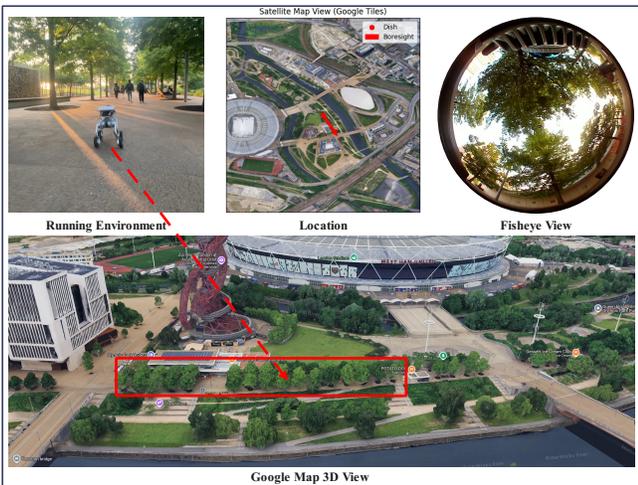


Figure 13. Environmental context and the robot running scenario in tree-covered area showing robot navigation through foliage-density paths with limited sky visibility.

Open Environment Performance: In unobstructed areas (Figure 11), Starlink exhibits fundamental LEO satellite characteristics. Figure 12 shows periodic RTT fluctuations between 20–40 ms, with a mean of 31.5 ms (± 3.1 ms, 95% CI) in open areas. In contrast, under tree-covered paths (Figure 15), RTT exhibits frequent spikes reaching 40–100 ms, with a mean of 56.4 ms (± 6.2 ms, 95% CI). These patterns remain highly regular, providing a performance baseline for mobile applications.

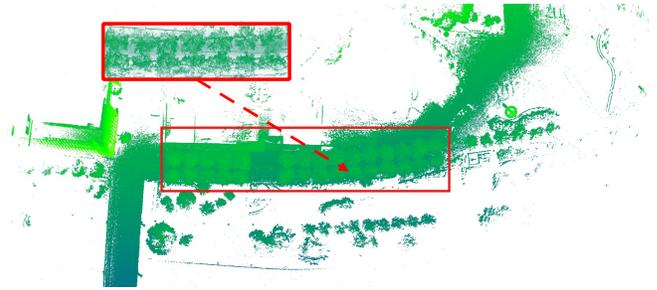


Figure 14. LiDAR point cloud visualization of tree-covered environment illustrating canopy density and potential signal obstruction patterns affecting satellite communication.

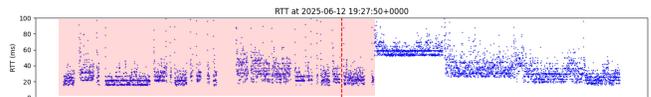


Figure 15. Communication performance in tree-covered environment demonstrating increased RTT instability and frequent spikes due to limited satellite visibility.

Obstructed Environment Challenges: Tree-lined streets (Figure 13) create dramatically different conditions. The LiDAR visualization (Figure 14) reveals how dense canopy limits sky visibility to narrow corridors. This constraint fundamentally alters communication dynamics, as shown in Figure 15: RTT exhibits severe instability with frequent spikes reaching 40–100ms. These degradations result from reduced satellite selection options, intermittent signal fluctuations through canopy gaps, and continuous parameter adjustments by obstruction detection algorithms.

Environmental Transitions: The most revealing insights emerge during transitions. When moving from tree cover to open areas, RTT stabilizes within seconds with baseline shifts of 10–20ms and variance reductions exceeding 50%. Unlike terrestrial networks that benefit from multipath propagation, satellite links exhibit binary behavior: sufficient sky visibility enables stable connection, while obstructions cause severe degradation. This distinction makes path planning crucial for mobile satellite applications, as even brief passages under obstructions can disrupt service entirely.

6 Research Opportunities and Conclusion

Our deployable platform and synchronized multi-modal dataset open up several concrete research opportunities in mobile sensing and networked systems. Specifically, they provide a foundation for exploring motion-aware networking and connectivity-aware navigation. Furthermore, the data can drive future studies on handover prediction and environment-aware adaptation, utilizing satellite telemetry and visual point clouds to optimize network policies under physical occlusions.

Our platform and dataset address this research gap by providing synchronized, multi-modal data to correlate communication metrics with motion and environmental context.

Open-sourcing these resources provides ground truth for developing adaptive protocols and supports community efforts toward seamless network integration.

7 Acknowledgment

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