Poster Abstract: Exploring Time-series Telemetry from CubeSats

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ABSTRACT

With increasing numbers of nano-satellites (CubeSats) being launched into space in recent years, monitoring their health and debugging become crucial problems. In traditional systems such as big satellites, time-series telemetry is widely used by users to monitor the state of the satellite from the ground stations. However, today smaller CubeSats do not enjoy the benefits of live telemetry due to low throughput and lack of coverage from ground station infrastructure. In this poster, we conduct a motivation study based on data collected from public satellites in low-earth orbit to demonstrate the potential bottlenecks in obtaining live telemetry data from CubeSats. We then describe the design space of possible solutions and opportunities for researchers to improve time-series telemetry for CubeSats.

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1 INTRODUCTION

As the costs for launching nano-satellites and CubeSats have reduced in recent years [1], many more of these cheap, low-power satellites are being launched into space in Low Earch Orbit (LEO). The typical size of a CubeSat is 10 $cm \times 10$ $cm \times 10$ cm (called 1U) and weighs roughly around 1 kg. A large fraction of these CubeSats are launched for research, education, and by hobbyists, primarily using off-the-shelf hardware for communication [6].

The ability to monitor the status of CubeSats becomes crucial after they are deployed in space. For example, a CMU-team made a recent launch of CubeSats in collaboration with NASA and found that three of the CubeSats launched were consuming much more power than expected [4]. In such a situation, it is important to identify the source of the issue to then enable a solution. In typical robust telemetry systems for large spacecrafts, end-users on the ground can easily obtain the history of the time-series data from sensors such as temperature, magnetic field and power generation, to diagnose and detect any hardware and software issues found. In contrast, the smaller CubeSats send sparse time-series data in the form of the current state every few minutes to the ground stations.

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This dichotomy between the ability to communicate time-series sensor data mainly originates from the following reasons:

(1) Limited Bandwidth: CubeSats suffer from power constraints to communicate enough telemetry data as power is only generated by small solar panels. This limits them to only communicate using low-throughput narrowband technologies such as LoRa with several kbps of available bandwidth downstream [3]. Further, much of the downlink payload is reserved for actual data payload which may further reduce the telemetry information downstream.

(2) Sparse Ground Station Coverage: One may argue that if we can continuously track the real-time sensor data sent by CubeSats, even limited bandwidth is good enough for the purpose of telemetry. However, because of the fast orbital speed of LEO satellites, a single ground station can only communicate with a CubeSat for about ten minutes per day per orbit [5]. The ground stations need to densely cover the earth to achieve such real time communication, but the cost of deploying large number of new base stations remains too impractical at the current scale of CubeSat deployment [7, 8].

Access to live telemetry can also enable users to further program the CubeSats based on their state, enabling new applications. Thus, we raise the following research question, "Can we provide the benefits of time-series telemetry that big satellites enjoy to LEO satellites?" In this poster, we conduct a motivation study by retrieving and decoding the time-series data from a public LEO satellites to understand how effectively we can obtain telemetry data from LEO satellites today. We then discuss potential solutions and challenges in using time-series compression to enable better telemetry for LEO satellites.

2 MOTIVATION STUDY

This section describes the motivation study to identify the limitations of CubeSat telemetry today. SatNOGS [2] is a open source global network of satellite ground stations, which includes a database containing crowd-sourced signals received from LEO satellites uploaded from these ground stations across the world. We develop a software pipeline to retrieve and decode this raw data from satellites to retrieve the time-series telemetry data. We then combine these measurements across the ground stations around the world to understand coverage and throughput bottlenecks of CubeSats while communicating with the pre-existing global ground infrastructure.

We demonstrate our pipeline on NOAA-19 satellite [10], that is one of the U.S. weather satellites operating in LEO. It uses the Automatic Picture Transmission (APT) [9] scheme to modulate its captured images as well as telemetry data into analog images and transmit to the ground. Fig. 1 shows the pipeline of how we retrieve the telemetry data from NOAA-19 based on SatNOGS database. The crowdsourced map in Fig. 1 also shows the ground station distribution in the SatNOGS network around the earth. We find that the ground stations are mainly concentrated in high-income nations in North America and Europe. Very few ground stations exist in

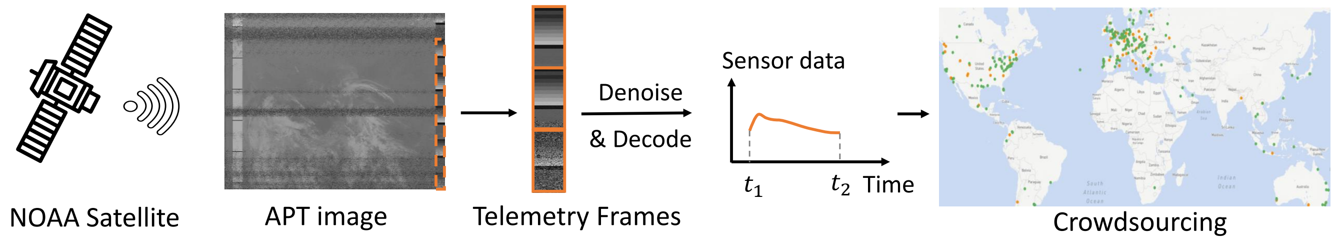

Figure 1: Pipeline to obtain NOAA satellites telemetry data. NOAA satellite encodes its captured image and telemetry sensor data into an APT image, and sends it to the ground. We capture the APT image on a ground station, decode and denoise the sensor data in each telemetry frame, and align it with the image timestamps. Finally, we perform crowdsourcing to combine the data across every ground station that received data from the satellite via SatNOGS network.

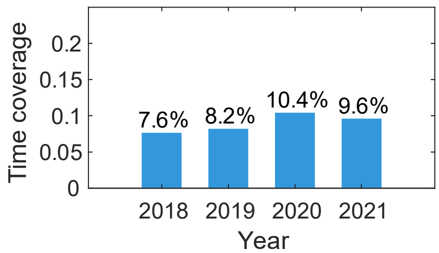

Figure 2: Time coverage (percent of time satellite data is available) for each year that the telemetry data is available

remote regions or the developing world. Such an imbalanced ground coverage may limit our ability to capture real-time telemetry data when monitoring a single satellite. Remember that while NOAA-19 is a larger satellite with dedicated ground infrastructure around the world, a smaller and cheaper CubeSat will likely face coverage bottlenecks in these locations.

We retrieve and decode three years data of NOAA-19 from Nov.10 2018 to Nov.9 2021, and calculate the span of time over which telemetry data is available from public non-dedicated ground stations – which we call time coverage. Fig. 2 shows that the time span of available telemetry data is slightly higher in the last two years, when compared to before, due to increase in deployment of ground stations in the SatNOGS framework. Yet, the 10% of time coverage remains too little for enabling real-time telemetry applications such as diagnosis and debugging on LEO satellites, especially CubeSats which lack dedicated ground infrastructure. This makes it imperative to develop a better approach for telemetry from CubeSats.

3 DESIGN SPACE AND CHALLENGES

Short of installing new ground stations, a natural starting point is to enable efficient time-series data compression so that CubeSat telemetry can be efficiently delivered to the next available ground station, which de-compresses the data. The challenge is to discover the precise form of efficient compression needed for CubeSat telemetry data under the stringent bandwidth limits.

It is likely that much of telemetry time-series data is quite sparse in specific domains, as these signals stem from actual mechanical and electrical systems that have a highly rhythmic behavior. A naive solution would be using deterministic basis such as DCT and DWT to transform and compress the signal. However, the telemetry signal is not necessarily be sparse in these domains, so these approaches may not be able to achieve satisfactory compression ratios. New data-driven techniques will be needed to push the limit of compression to meet the tight bandwidth constraints while remaining agile to these sparse basis.

Most data-driven techniques that estimate the optimal basis of data using techniques such as PCA, require full access to the raw data. However, in our case, only one end has the access to the raw data – the resource-constrained CubeSats. Thus, the CubeSat does not have enough compute and memory resources to perform such heavy data-driven techniques. On the other hand, the base station has large resources (with access to cloud compute and storage), but it does not have the access to the data stuck at the client. This motivates potential solutions such as compressive sensing or lightweight deep learning models that can also be designed to leverage similar asymmetries. However, we leave the precise designs of such solutions as an open challenge for future researchers.

4 CONCLUSION

This poster highlights an important open research problem in retrieving time-series telemetry from CubeSats. Our motivation study based on NOAA-19 telemetry data on SatNOGS database finds that the starved bandwidth and sparse ground station coverage limits the performance of current LEO satellite telemetry. We further explore the design space of solutions on time-series compression and discuss the related challenges and future work in this space.

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