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Monitoring Satellite Pattern-of-Life Changes with Passive Radio Frequency Data

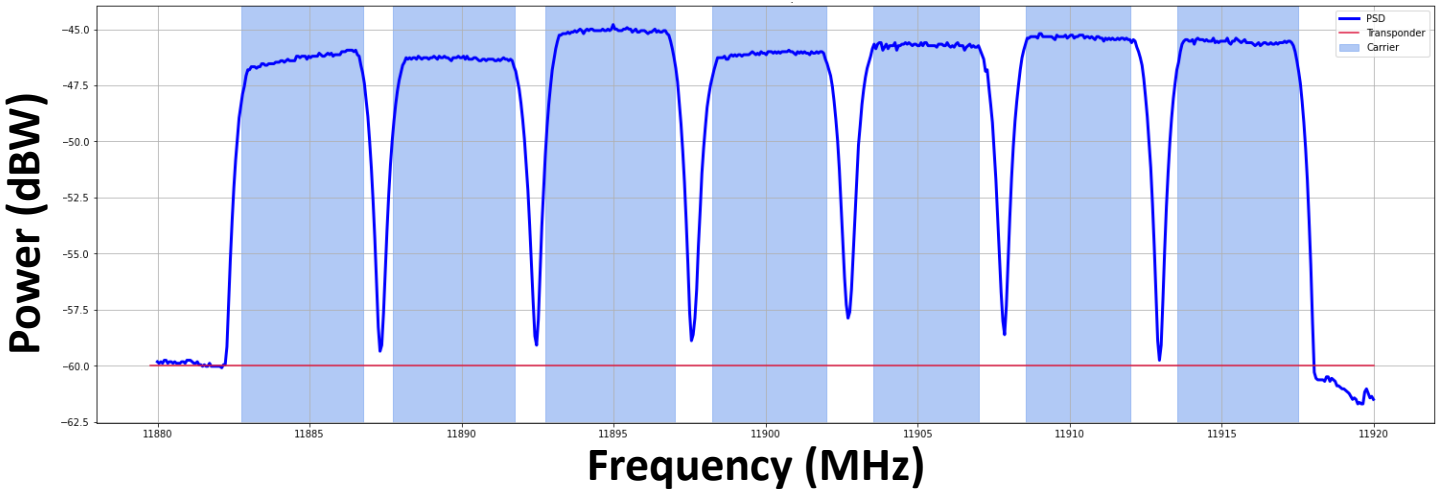
GSAW 2024

Introduction

- Radio Frequency (RF) Overview
- Building Pattern-of-Life for RF Datasets
- Real-World Example 1: Eutelsat Hotbird 13B
- Real-World Example 2: SES-1
- Real-World Example 3: Yamal 401
- Conclusion

RF Overview

- **Transponder:** A communication unit that receives data from an antenna and then transmits that data to a different antenna
- **Carrier:** A signal that a transponder emits; carriers are modulated signals that carry data between ground stations
- **Power Spectral Density (PSD):** A way to visualize RF data



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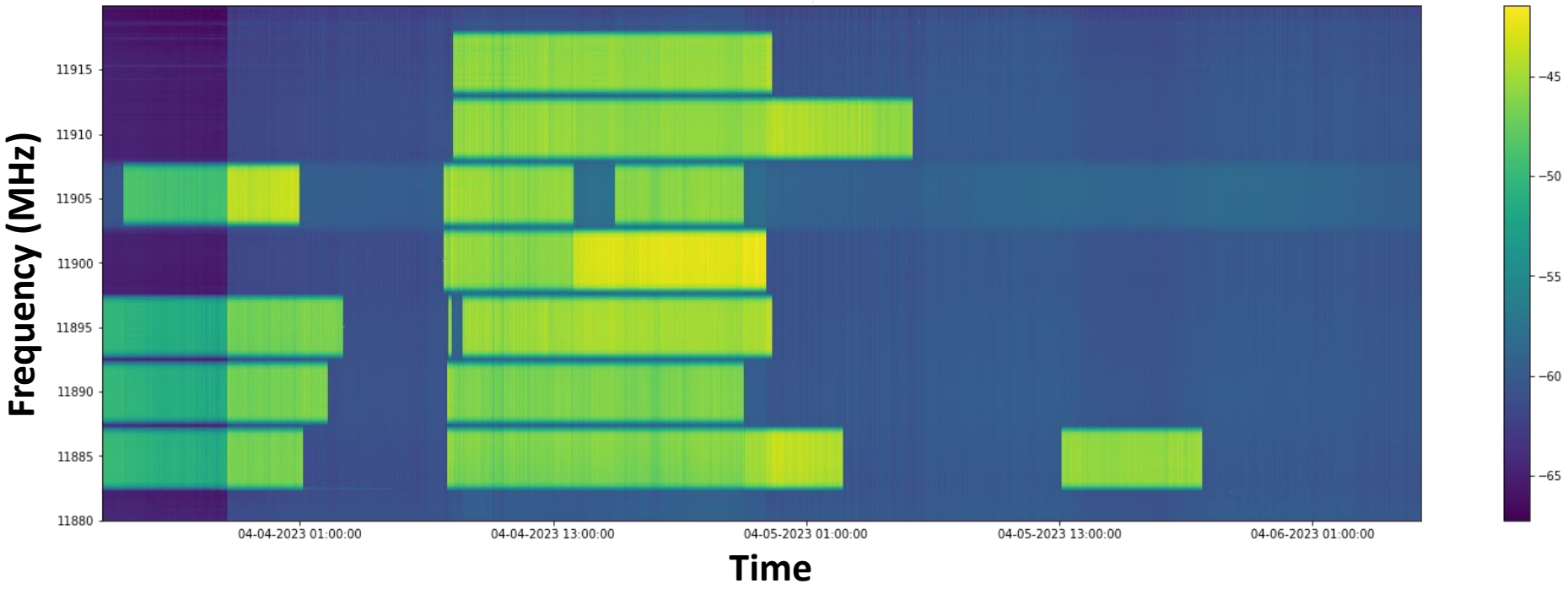
RF Overview

Waterfall Plot of Transponder 10K on SES-1



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Building Pattern-of-Life for RF Datasets

- Goal is to create a model that is:
  - Able to find anomalies in RF metrics trended over time
  - Easily customizable for different use cases
  - Fast

- **Statistical**
  - Smoothing
    - Exponential Average
  - Anomaly Detection
    - Rolling Gaussian
- **Time Series**
  - ARIMA
  - Ruptures
- **Machine Learning**
  - Vanilla LSTM
  - Autoencoder
  - Autoencoder with LSTM Layers

Building Pattern-of-Life for RF Datasets

- **Ensemble Model**
  - All 3 models are run on same time series dataset
  - If majority (2/3) identifies a point is anomalous, it is flagged as an anomaly
- **Operational Workflow**
  - Run all models (with all window sizes and a variety of hyperparameters) on dataset
  - Visualize all results
  - RF Analyst chooses which models the ensemble model is comprised of

Real World Example 1: Eutelsat Hotbird 13B

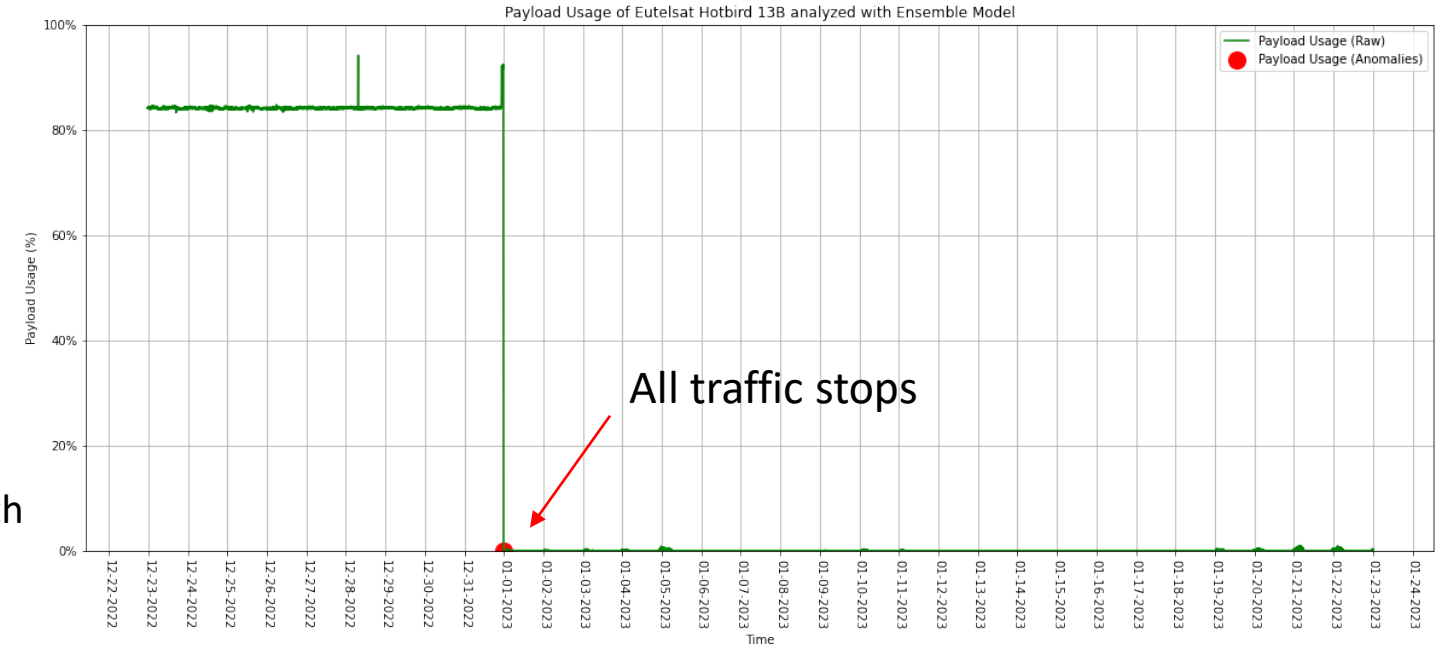
Direct-to-Home TV broadcast Satellite (12/22/22 to 1/24/23, Transponder 116)

Payload Usage:

$$\frac{\sum_{i=0}^{n} b_{c,i}}{b_t}$$ where

b_t = Transponder Bandwidth and

b_c = Carrier Bandwidth



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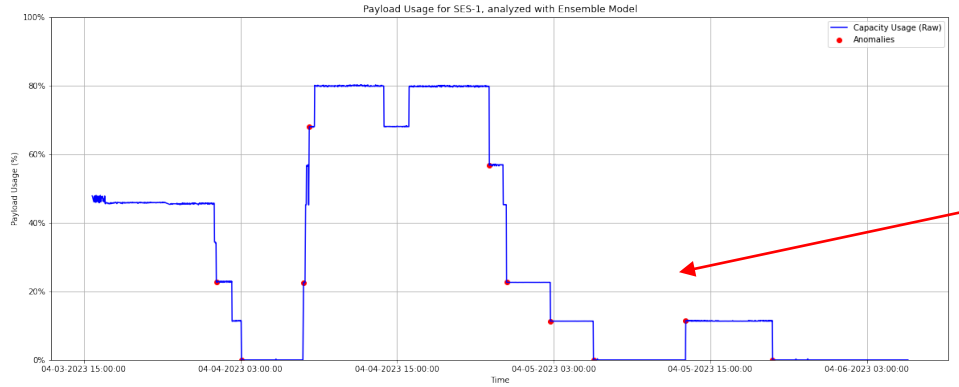
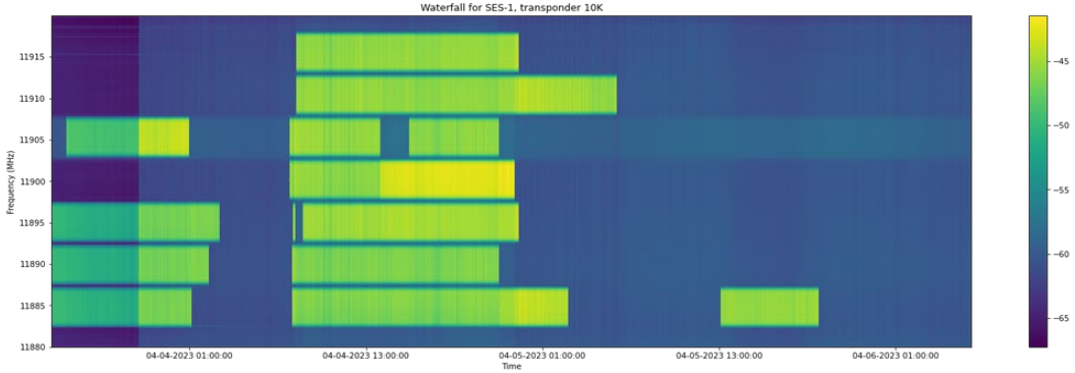
Real World Example 2: SES-1

Communications Satellite (4/3/23 to 4/6/23, Transponder 10K)





Anomalous changes perfectly coincide with carriers coming up and going down

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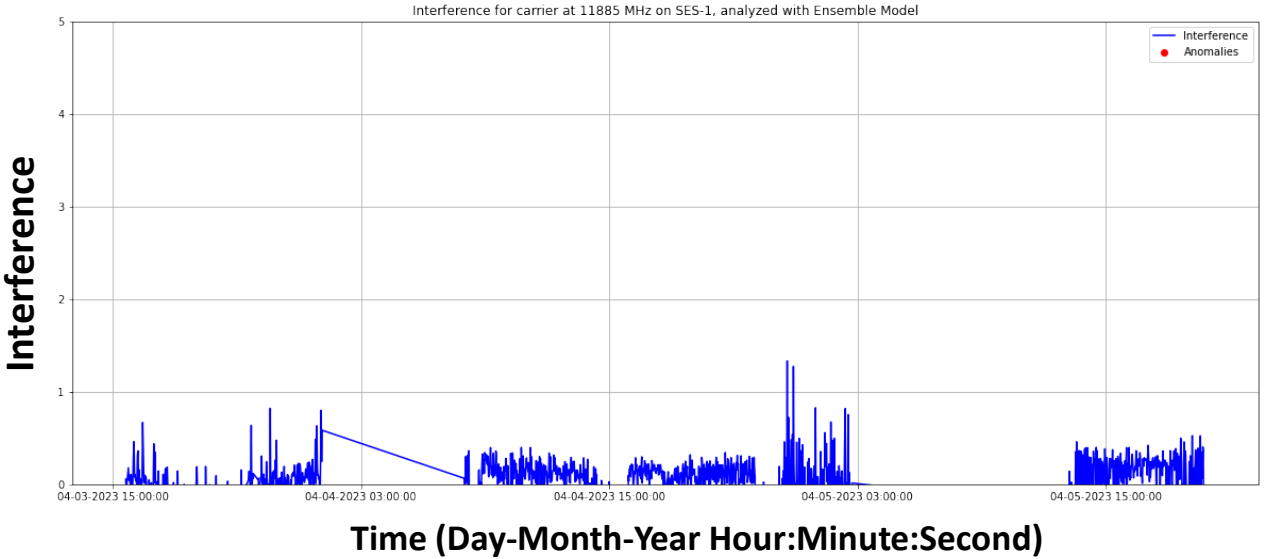
Real World Example 2: SES-1

- An RF analyst would begin to look at the carrier metrics

Interference Metric:

$$\frac{C}{N} - \frac{E_S}{N_0}$$ [1]

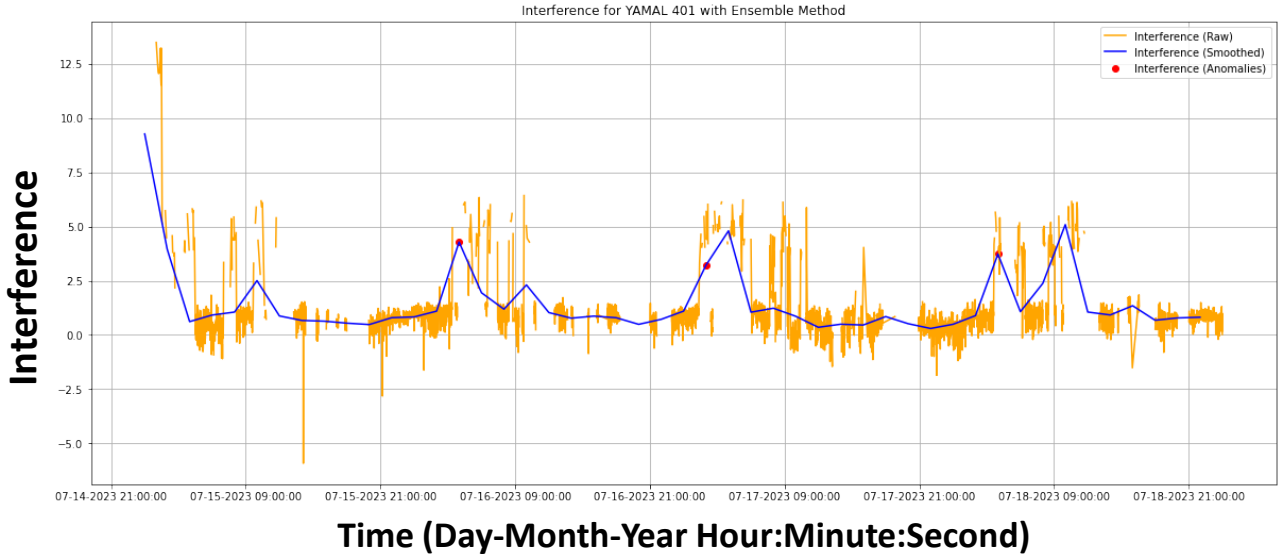


No anomalies detected, so no malicious behavior here.

[1] See corresponding paper for more details.

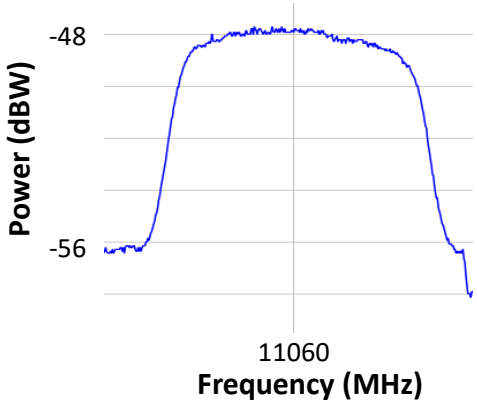
Real World Example 3: Yamal 401

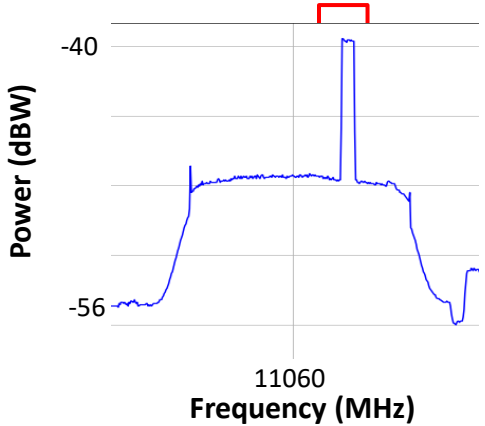
Russian Communications Satellite (7/14/23 to 7/18/23)

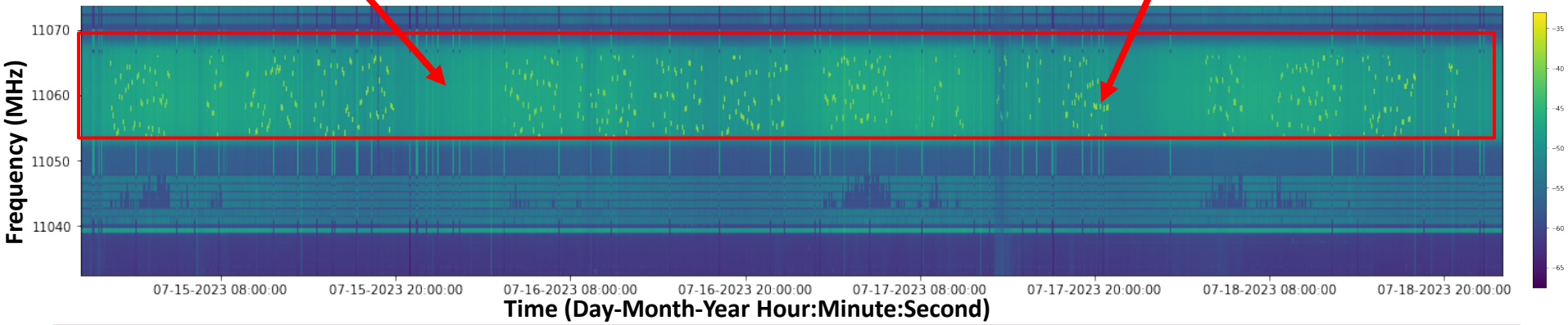


- Several anomalies detected for carrier at 11060 MHz

Real World Example 3: Yamal 401







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Conclusion

- Passive RF pattern-of-life analysis
  - Can contribute to the SDA mission by giving insights into payload behavior
  - Can be used to construct a transponder/carrier's pattern-of-life and detect abnormal behavior
  - Is a valuable tool to RF Analysts due to its functionality, customization, and scalability
  - Is phenomenology agnostic and can be used on any time series dataset

Thank You