State Predictor of Classification Cognitive Engine Applied to Channel Fading

Presented by:

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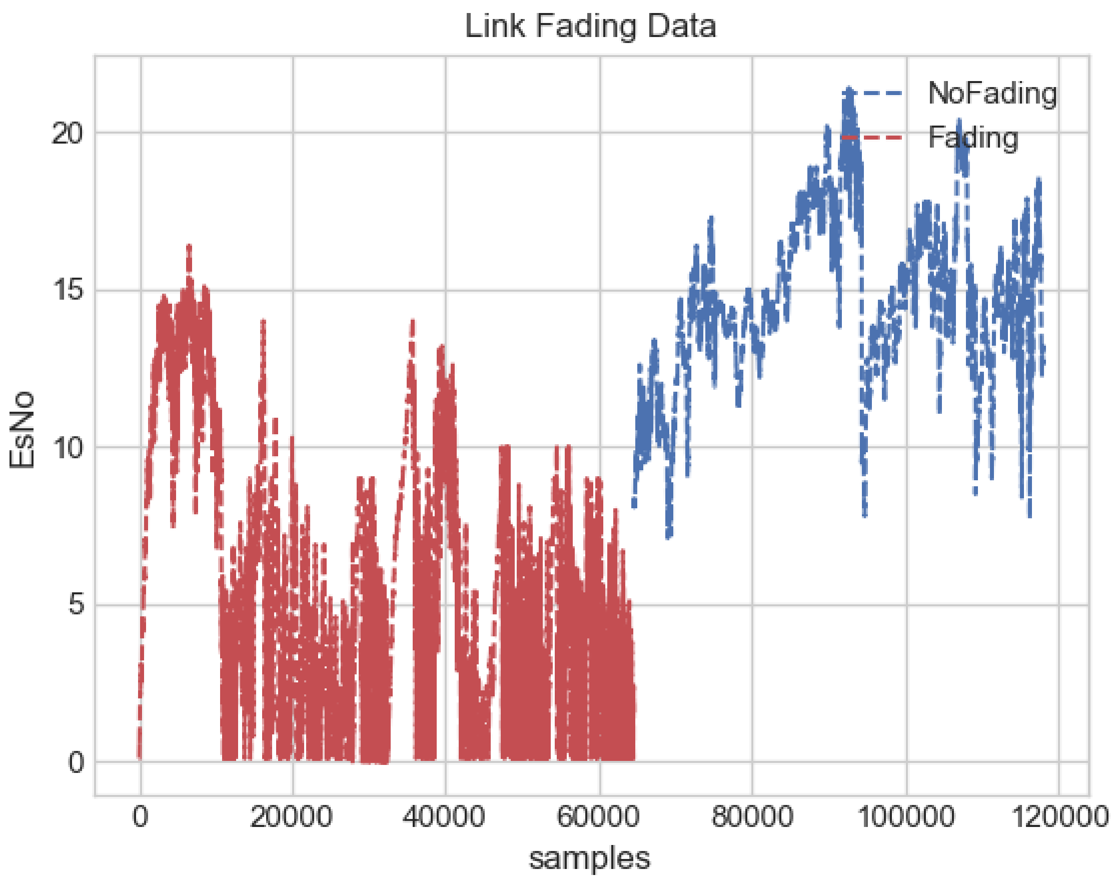
Overview

- This study presents the application of machine learning (ML) to a space-to-ground communication link, showing how ML can be used to detect the presence of detrimental channel fading. Based on this this channel state information, the communication link can be used more efficiently by reducing the amount of lost data during fading.
- The motivation for this work is based on channel fading observed during on-orbit operations with NASA's Space Communication and Navigation (SCaN) testbed on the International Space Station (ISS).
- This work presents the process to extract a target concept (fading and not-fading) from the raw data. The pre-processing and data exploration effort is explained in detail, with a list of assumptions made for parsing and labelling the dataset.
- The model selection process is explained, specifically emphasizing the benefits of using an ensemble of algorithms with majority voting for binary classification of the channel state.
- Experimental results are shown, highlighting how an end-to-end communication system can utilize knowledge of the channel fading status to identity fading and take appropriate action. With a laboratory testbed to emulate channel fading, the overall performance is compared to standard adaptive methods without fading knowledge, such as adaptive coding and modulation.

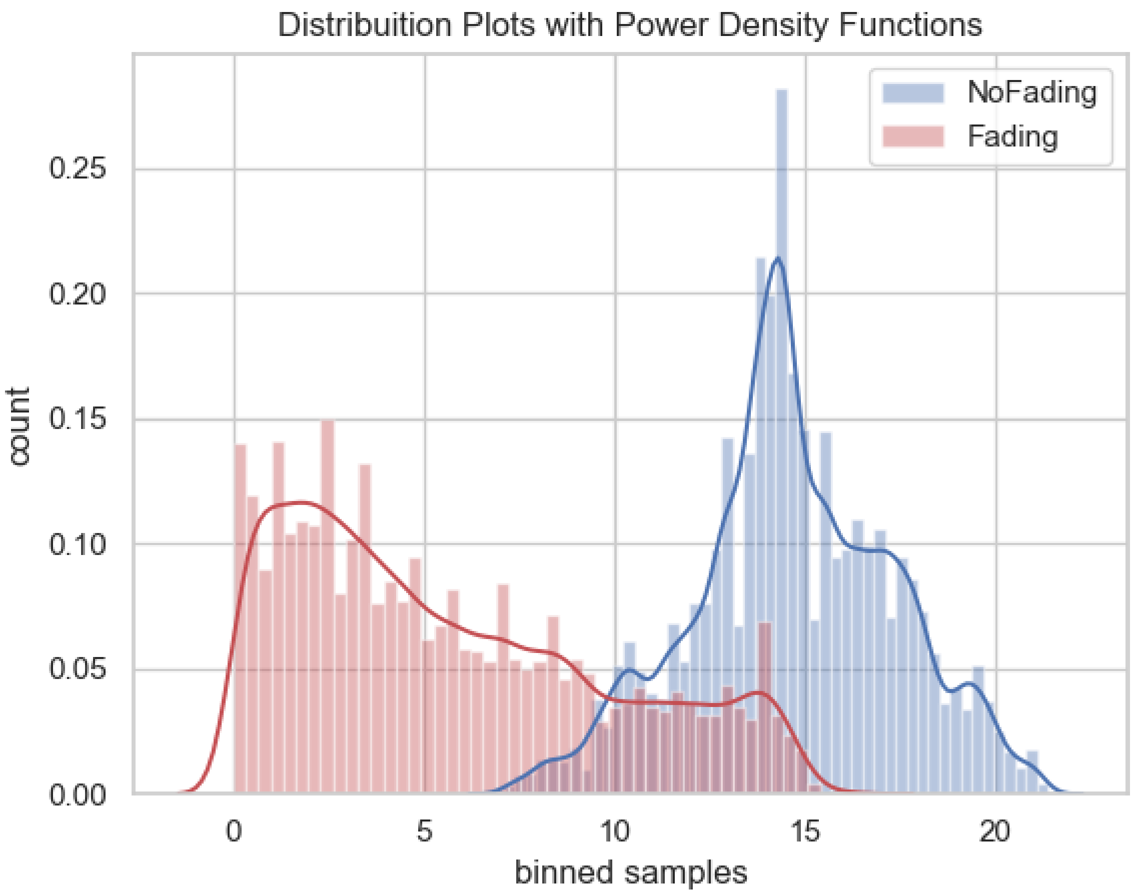
Data Pre-Processing

- A number of events have been recorded from direct-to-Earth communication events between the SCaN Testbed on ISS and the GRC ground station.
- Link metrics are routinely captured at the ground station including the modem's estimated Es/No (energy per symbol to power spectral density) versus time, at a rate of 100 Hz.
- A number of these profiles were collected and concatenated yielding a total number of 117935 Es /No values labelled as "Fading" or "NoFading". This data is plotted on the right
- This nomenclature was chosen to distinguish between classes, that represent
  - Rapid fluctuation of the amplitudes or high oscillation,
  - Signal that has been received but is otherwise unable to be decoded due to high noise floor or other issues.



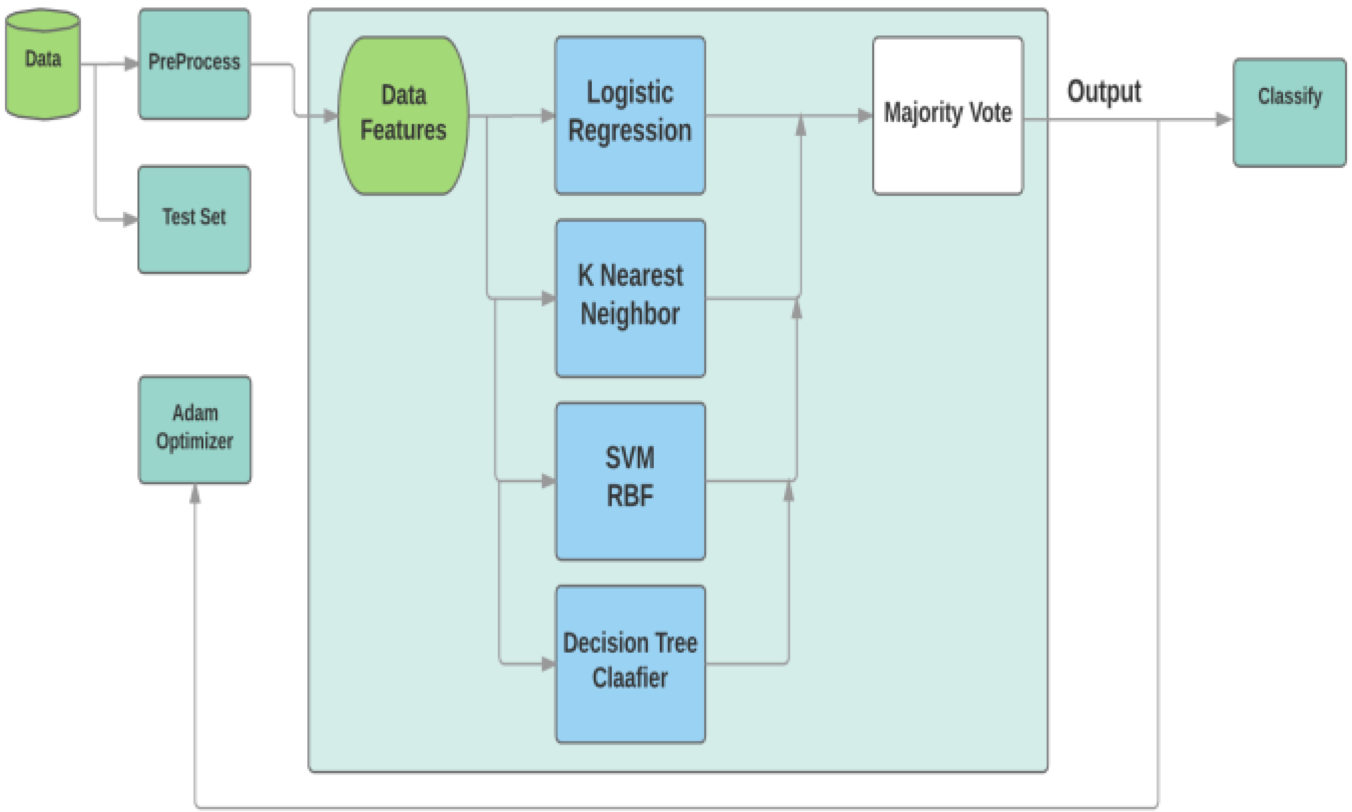
Data Exploration

- Data exploration was performed to determine the best approach for creating a model capable of defining the target class in situ
- A distribution plot of the two subsets was created to understand their characteristic similarities or differences as shown on the right.
    - *1). Raster the data with a window of 100 samples, 2). Calculate mean, median, variance and kurtosis for each window, 3). Label each rastered segment based on its class label within the database*
- Then an 80/20 train/test split was done on the remaining samples and the process moved on to model selection and grid search for hyperparameter optimization.



Model Selection

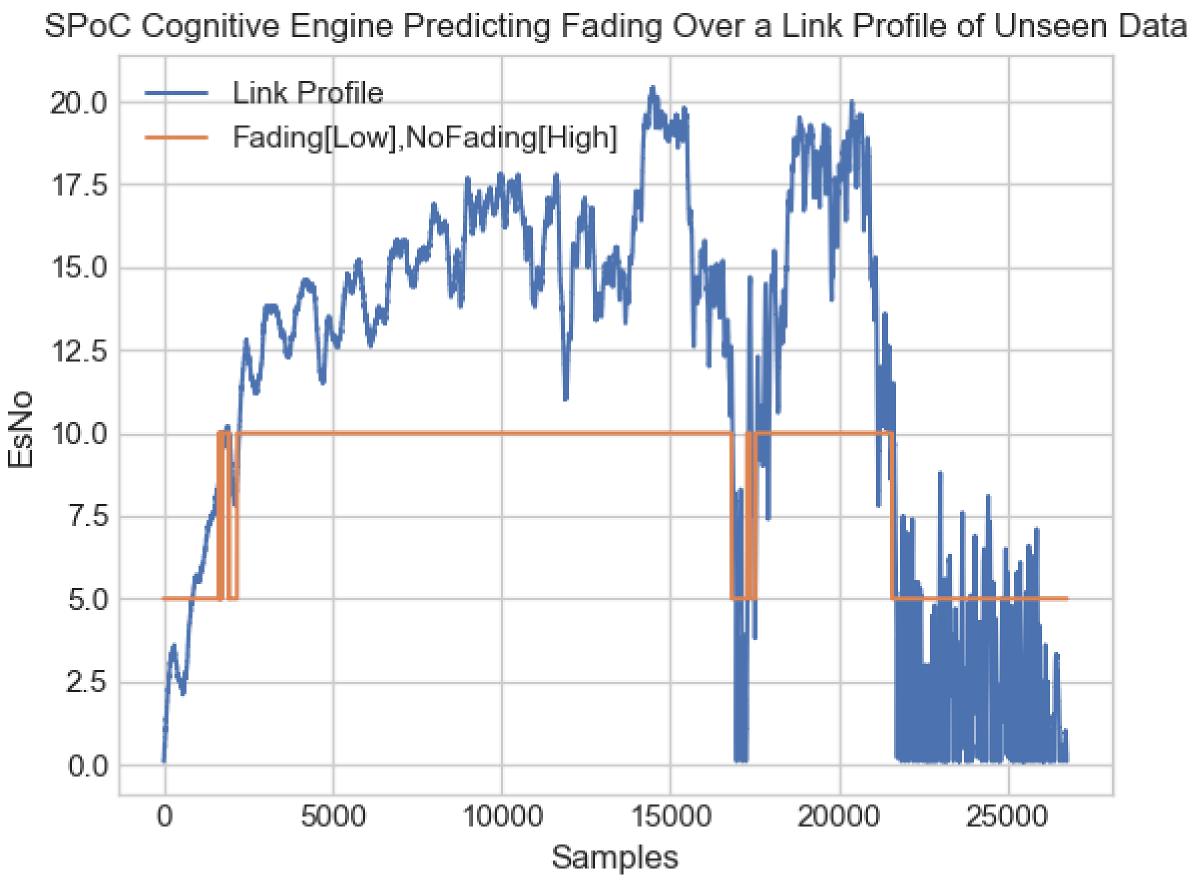
Method Name	*Precision*	*Recall*	*F1-Score*
Naïve Bayes	0.73	0.77	0.75
Linear Discriminant Analysis	0.79	0.76	0.76
Logistic Regression	0.91	0.91	0.91
K nearest neighbor (k=2)	0.68	0.62	0.65
K nearest neighbor (k=10)	0.88	0.88	0.88
K nearest neighbor (k=4)	0.92	0.94	0.93
Support Vector Machine (SVM)	0.94	0.98	0.96
Decision Tree	0.92	0.91	0.91
Learned Vector Quantization (LVQ)	0.78	0.77	0.77
Kernel Regression (Weighted)	0.65	0.69	0.67
Ensemble 1 (SPoC) version 1	0.96	0.94	0.95
Ensemble 2 (SPoC) version 2	0.99	0.99	0.99



Algorithm Verification

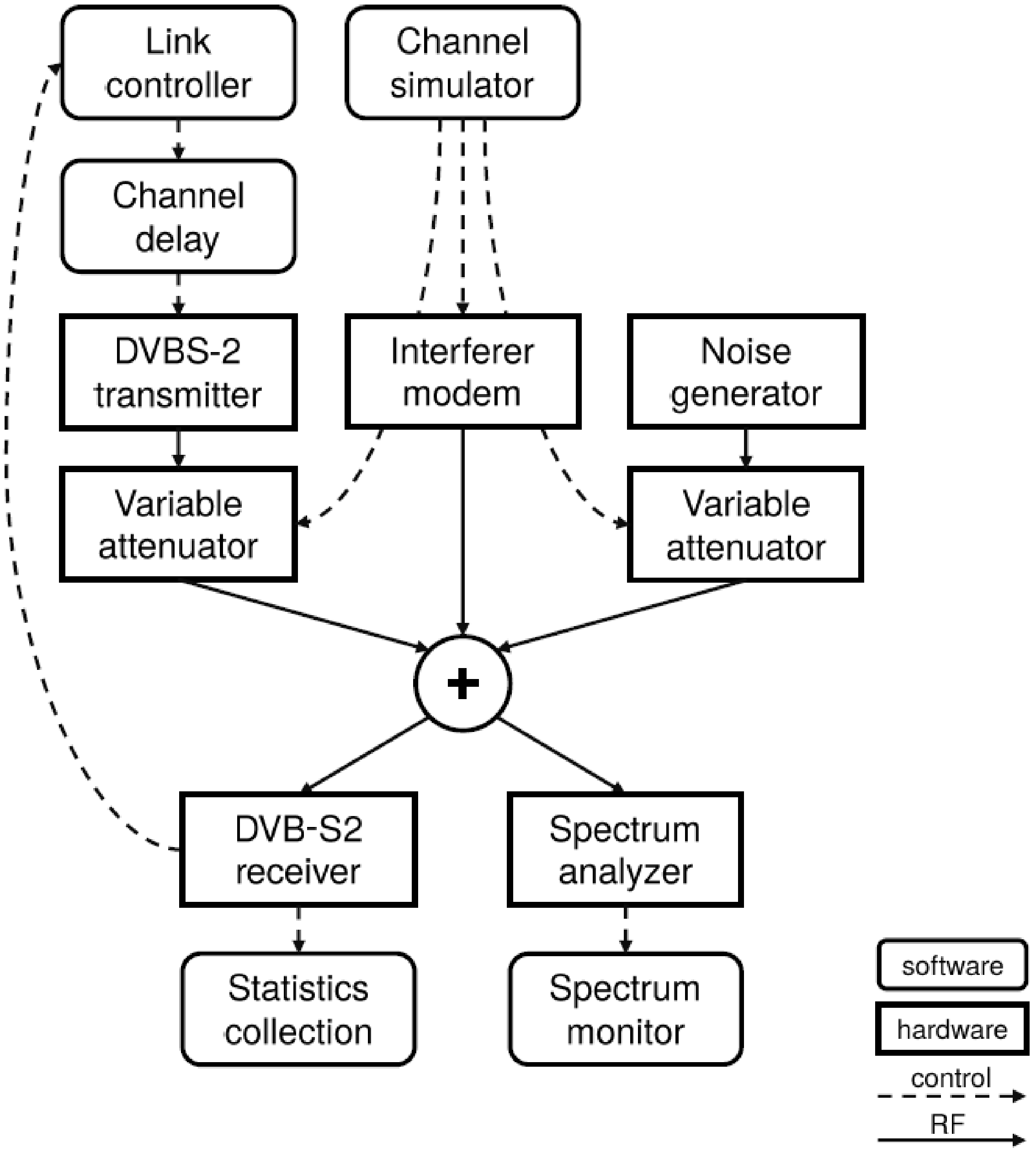
Confusion Matrix	*Counts*
True Positives	11279
False Positives	214
True Negatives	13514
False Negatives	73

- SPoC was run using the test data set and an independent profile
- The results from the test dataset is shown in the table above. As observed, the algorithm was able to correctly classify the test data 99% of the time. T
- A profile (shown right) was played back using a link emulator that mimics a space link for real time testing. SPoC was able to classify its state correctly and predicted the desired action on that state



Testbed SetUp

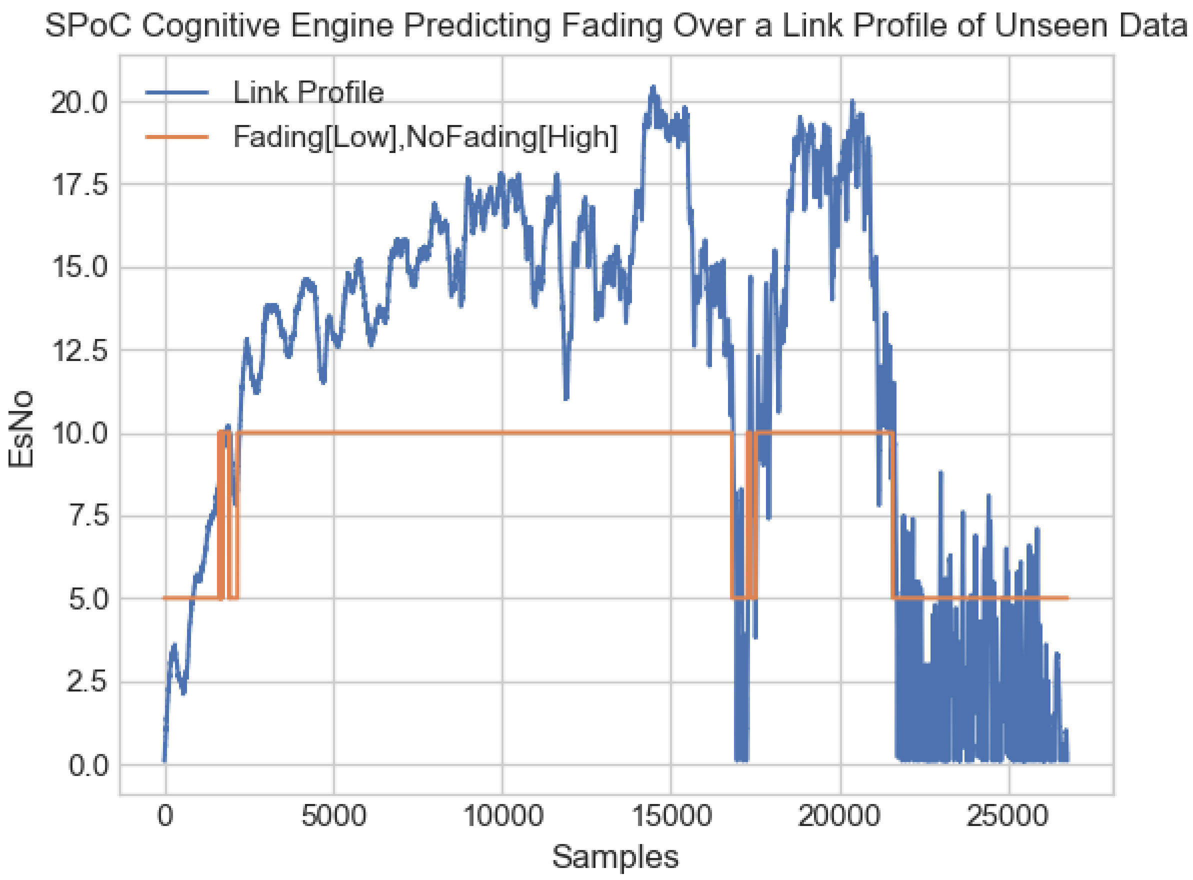
- Performance of the SPoC CE was evaluated using a laboratory testbed to measure the impact to the overall end-to-end communication system.
- This process was performed to validate the algorithm within its expected operational environment.
- The testbed emulates a satellite telemetry DVB-S2 link similar to the SCaN Testbed scenario, and features programmable RF interference, noise, and channel fading



Results

Algorithm	*Total Valid Frames*			*Total Dropped Frames*		
	12ms	**40ms**	**500ms**	**12ms**	**40ms**	**500ms**
ACM	16.9e6	16.9e6	16.6e6	7.7e2	3.1e3	3.5e6
ACM-XM	13.3e6	13.3e6	13.2e6	0	0	0.5e6
SPoC	13.2e6	13.2e6	13.1e6	0	23	1.5e6

- A total of 29 direct-to-Earth communication events were run
- Compared to the baseline ACM algorithm, there is approximately a 20% reduction in total throughput by using SPoC.
- Some reduction in throughput is expected, since the system does not attempt to send any data during fading.



Discussions

- The procedure followed in this study is a blueprint for the use of ML in data processing and creating applications that work with space communication links.
- The proposed method carries certain benefits for a link controller experiencing this type of channel fading.
- Developing SPoC as an ensemble of supervised learning models provides the ability to retrain the system and perform hyperparameter tuning in a straight forward manner.
- There are some drawbacks to the use of the presented process and SPoC, such as: the feature engineering necessary for data processing and labelling and the need to have a database with labeled classes ahead of time. There might be applications where such data is not available or not labelled properly for the system to train on.
- Overall, the use case of SPoC would allow for links coming from ISS to be shut off if high fading is present. Currently there is no implemented method for detecting this issue on SCaN testbed, so SPoC presents another node for controlling the link
- The ability to detect channel states has additional advantages for links such as those from ISS to the ground. Such as system can be used to automatically determine appropriate times to transmit data, without requiring manual human intervention to determine the schedule.

Conclusions

- This study presented the application of machine learning to a space to ground communication link.
- It was shown that ML can be used to detect the presence of fading in that link, given certain conditions.
- A detailed description of how the system is able to detect changes in link characteristics was provided and the study presented a process for extracting a target concept from the raw data both a-posteriori and in-situ.
- It was observed that both methods (with and without ML) perform well. Yet, using the ML method, the system was able to reduce the number of dropped frames over the adaptive method (without ML) with a reduced data throughput.
- This study is a proof of concept for using ML in space communications. This study highlights how ML methods can be implemented at the link level of the SCaN infrastructure, presenting both benefits and drawbacks.

Questions?