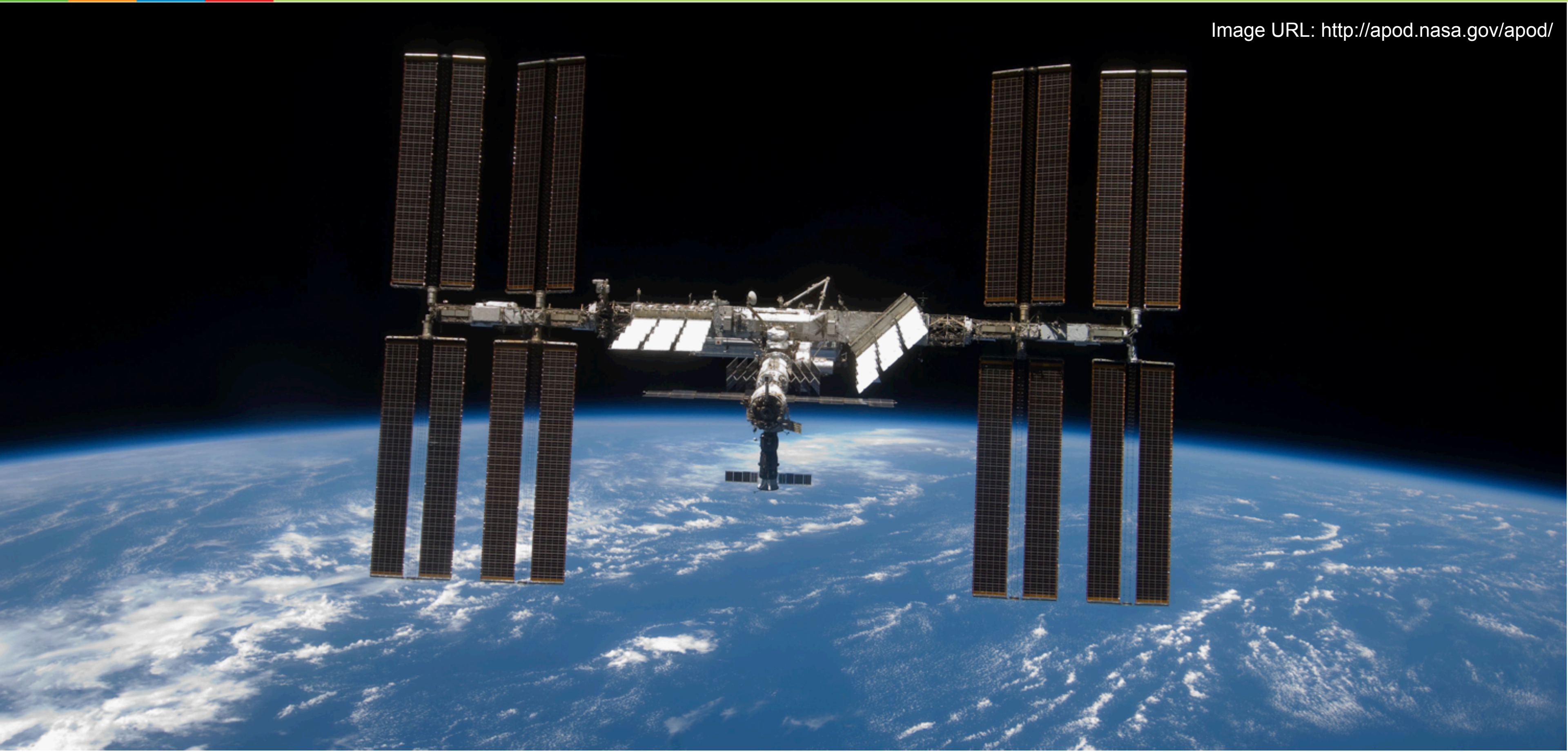
Adaptive Coding and Modulation Experiment with NASA's Space Communication and Navigation Testbed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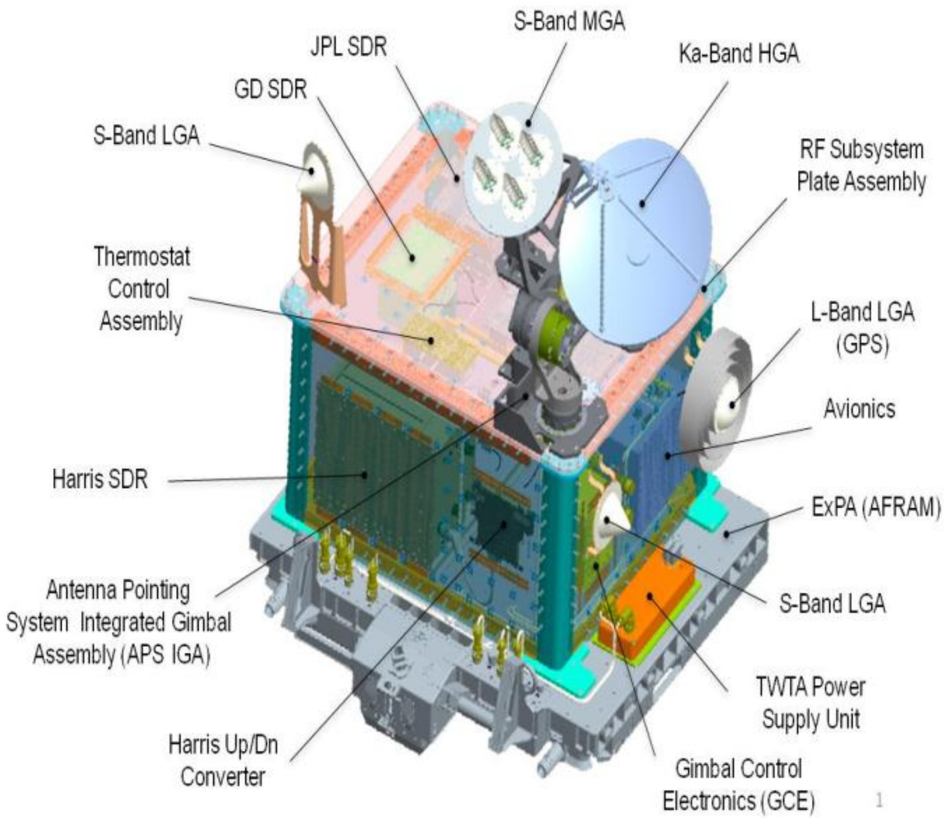
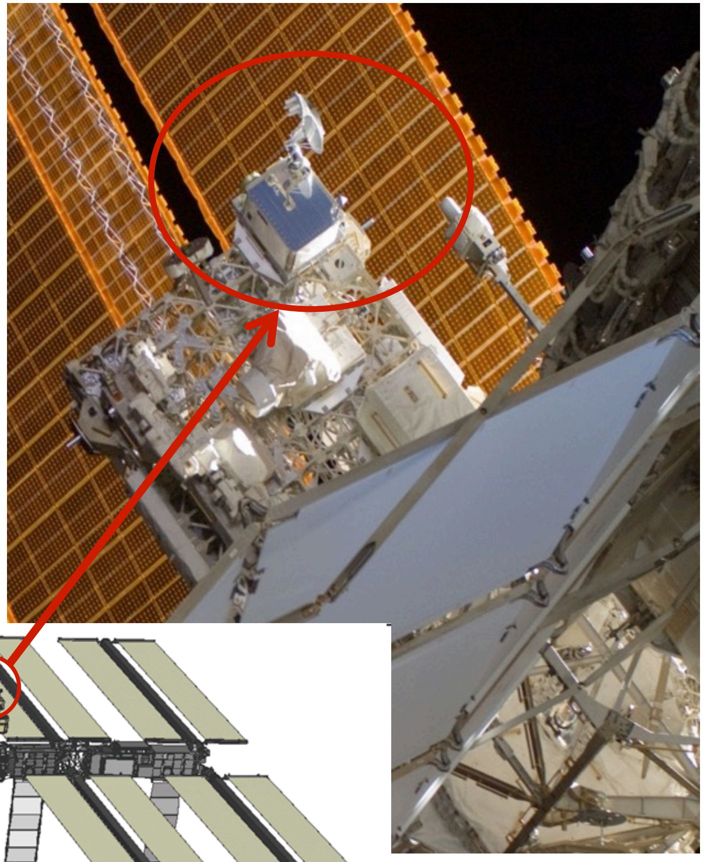
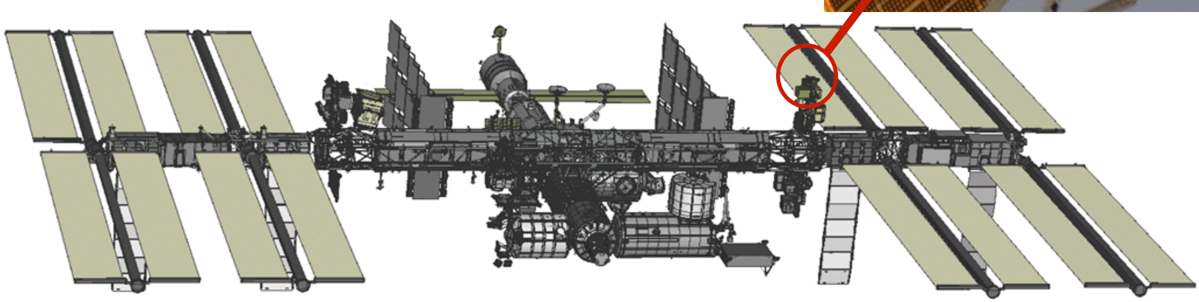
Presentation Outline

- Experiment Motivation
- Test Scenario and System Architecture
- On-orbit Test Results
- Summary
- Future Work

SCaN Testbed Overview







Experiment Goals and Objectives

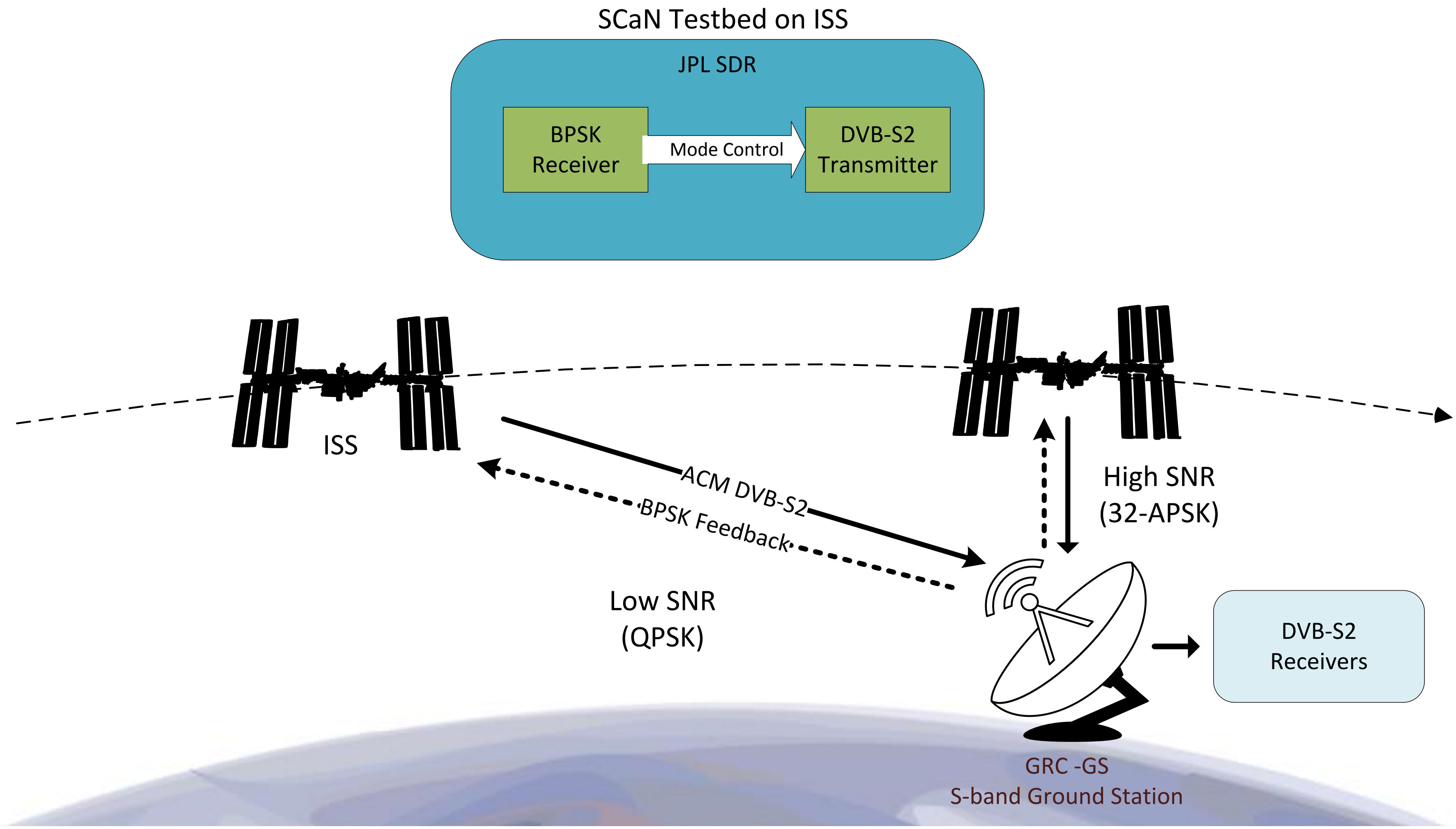
- Demonstrate the Digital Video Broadcasting - Satellite - Second Generation (DVB-S2) standard using commercial off-the-shelf (COTS) receivers, and determine feasibility going forward as a low-cost, high performance option for NASA's communication systems.

- Evaluate the Adaptive Coding and Modulation (ACM) features of the DVB-S2 standard, and quantify data throughput gains over traditional Constant Coding and Modulation (CCM) operational modes used by NASA.

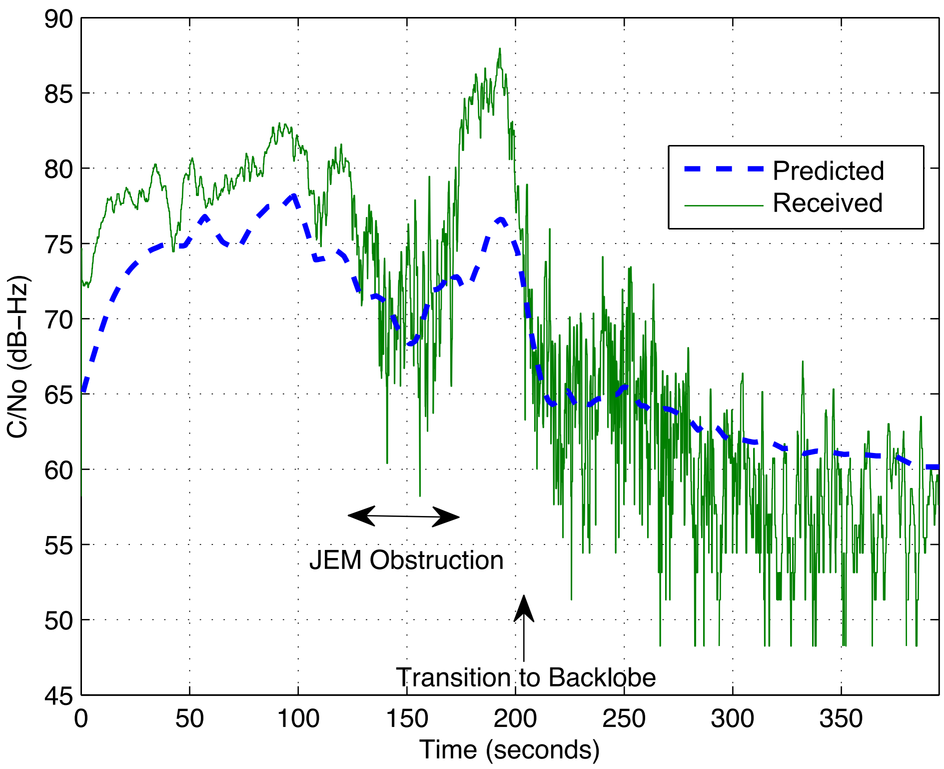
- Extend upon previous Variable Coding and Modulation (VCM) testing[1] and seek to further improve link reliability and efficiency, as well as increase operational automation.

- Create a software test platform for other developers to demonstrate more complex adaptive / cognitive algorithms using the DVB-S2 standard.

End-to-End System Block Diagram



Typical Direct-to-Ground Pass



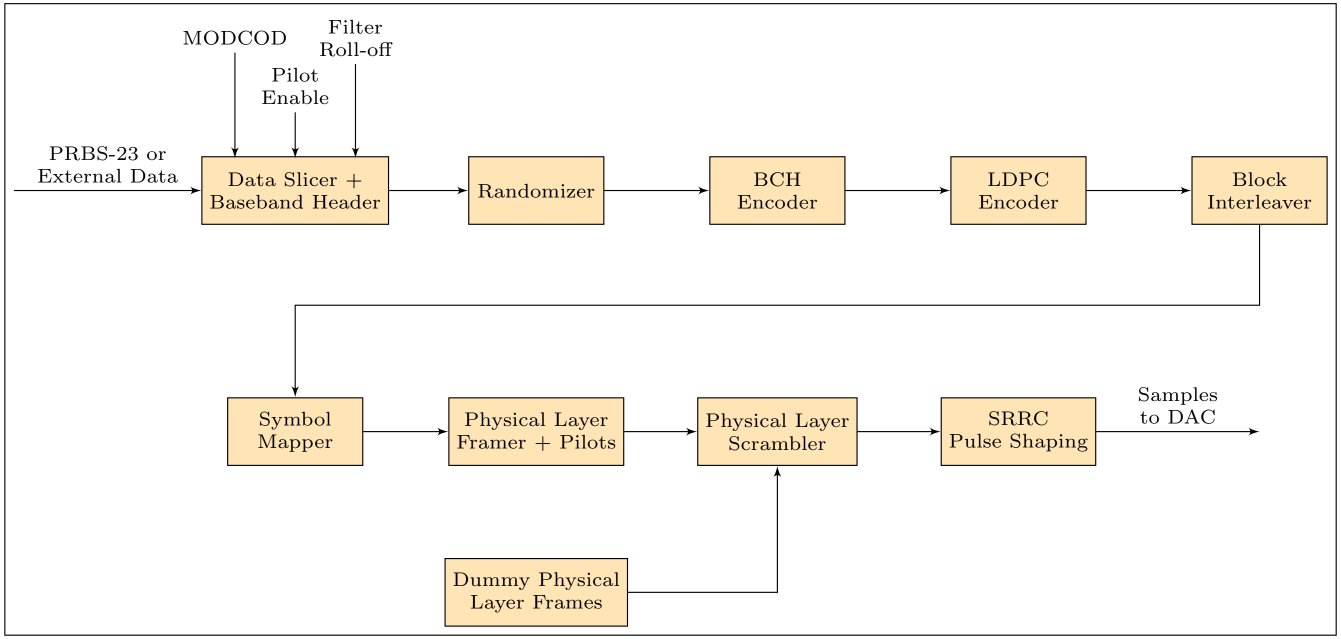
See [2] for Prediction Model Information

Sources of Signal Degradation:

- Multipath interference
- Non-line-of-sight propagation due to physical obstructions on ISS

Downlink Waveform: DVB-S2

- Waveform Configuration Information:
  - Supports up to 6.125Mbaud
  - Square Root Raised Cosine, α = 0.20, 0.25, 0.35
  - Framing Protocol: CCSDS 732.0-B-2
- 73% of Slices used on 3M Virtex-II
- Available in STRS Repository



Mode Identifier:	MODCOD #:	Spectral Efficiency (bpcu):
QPSK, r=1/4	1	0.36
QPSK, r=1/3	2	0.62
QPSK, r=2/5	3	0.74
QPSK, r=1/2	4	0.83
QPSK, r=3/5	5	1.13
QPSK, r=2/3	6	1.26
QPSK, r=3/4	7	1.39
QPSK, r=4/5	8	1.48
QPSK, r=5/6	9	1.56
QPSK, r=8/9	10	1.69
8PSK, r=3/5	12	1.69
8PSK, r=2/3	13	1.88
8PSK, r=3/4	14	2.08
8PSK, r=5/6	15	2.34
8PSK, r=8/9	16	2.53
16APSK, r=2/3	18	2.51
16APSK, r=3/4	19	2.76
16APSK, r=4/5	20	2.93
16APSK, r=5/6	21	3.10
16APSK, r=8/9	22	3.36
32APSK, r=3/4	24	3.42
32APSK, r=4/5	25	3.63
32APSK, r=5/6	26	3.84
32APSK, r=8/9	27	4.16

*Short FEC Frames w/ Pilots Enabled

Uplink Waveform: GGT Receiver

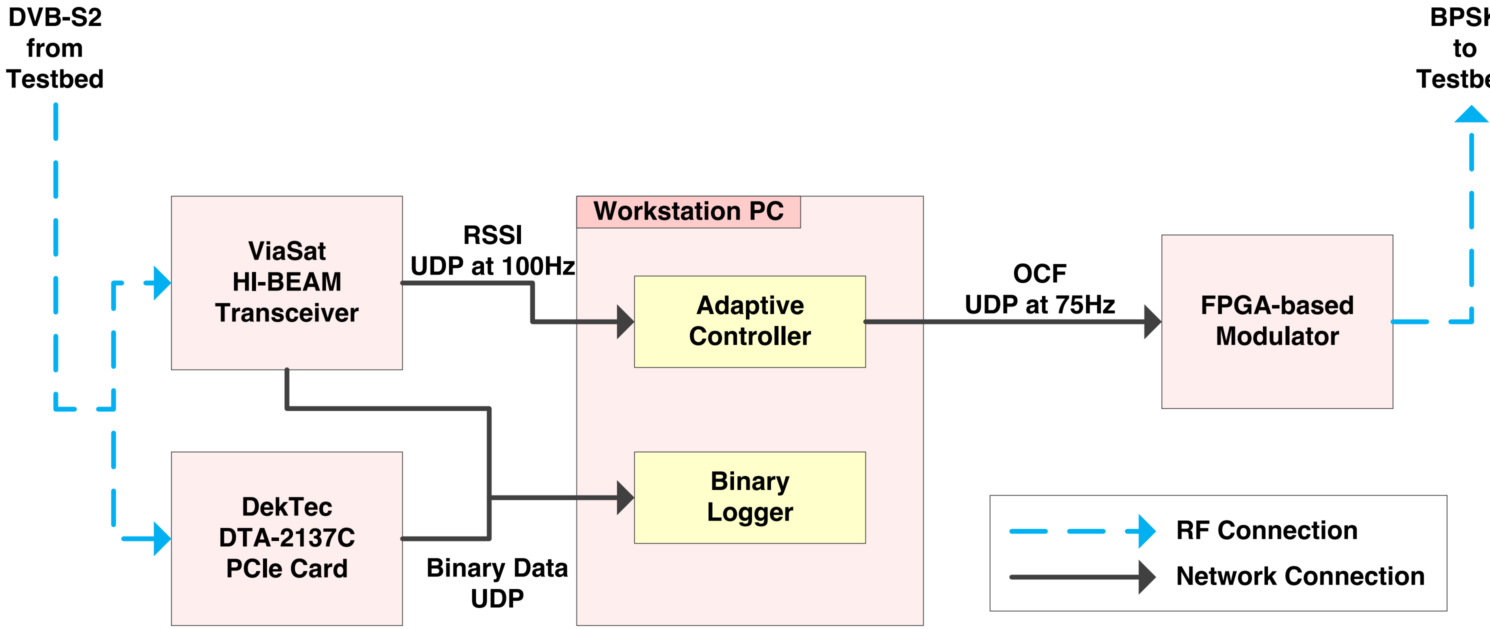
- Waveform Configuration Information:
  - Modulation/FEC: BPSK, 155.346kbps, r=1/2 convolutional code
  - Framing Protocol: CCSDS 732.0-B-2
- 71% of Slices used on 3M Virtex-II
- Available in STRS Repository

Attached Sync Marker (32 bits)	Transfer Frame Primary Header (48 bits)	Transfer Frame Data Field (1952 bits)	Transfer Frame Trailer	
			Operational Control Field (32 bits)	Frame Error Control Field (16 bits)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Type Flag (2 bits)											MODCOD (5 bits)												Pilot Enable (1 bit)							Roll-off Factor (2 bits)	

Ground System Components

- COTS Receivers
  - Allow for evaluation of end-to-end system using low-cost, readily-available items
- Adaptive Controller
  - Translates current Es/No into highest spectral efficiency MODCOD with FER $\leq 10^{-5}$
  - Inherently requires modem characterization across MODCODs and symbol rates
- Ground Software
  - Used to automate data capture and present real-time statistics, including FER/BER



Results from On-Orbit Testing

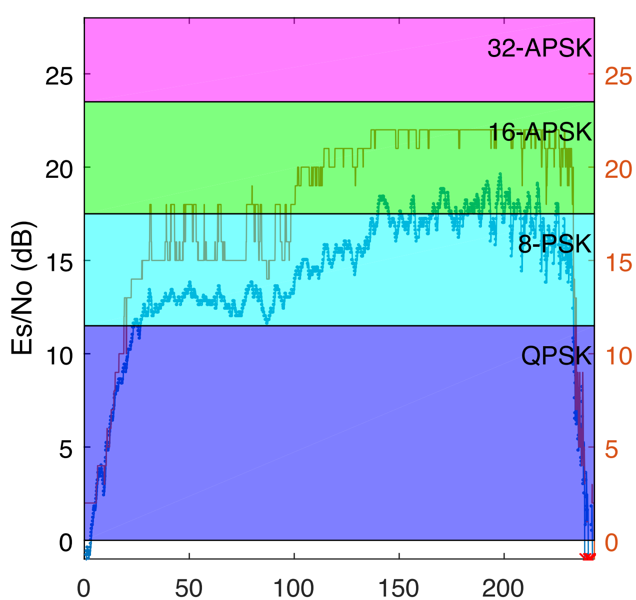
Cumulative Bit Error Rates*

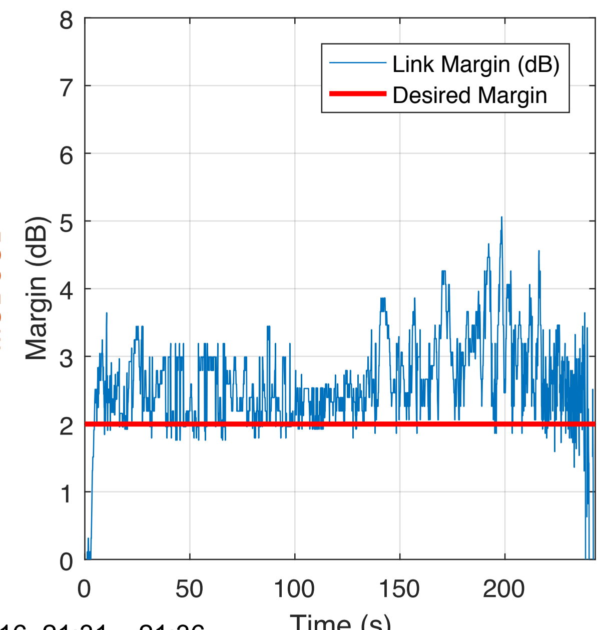
Event Number	BER
1	1.28E-06
2	2.41E-07
3	1.79E-06
4	2.23E-06
5	2.51E-08
6	7.67E-07
7	4.09E-07
8	5.34E-07
9	1.76E-06
10	1.50E-06
11	1.37E-06
12	1.68E-06

*To maximize throughput, event duration was not trimmed.

Data Throughput Improvement of ACM

Event Statistics	ACM vs. VCM	ACM vs. Ideal	ACM vs. Legacy NASA
Average	1.62dB	-0.23dB	4.34dB
Maximum	3.62dB	-0.12dB	5.42dB
Minimum	0.26dB	-0.43dB	3.42dB

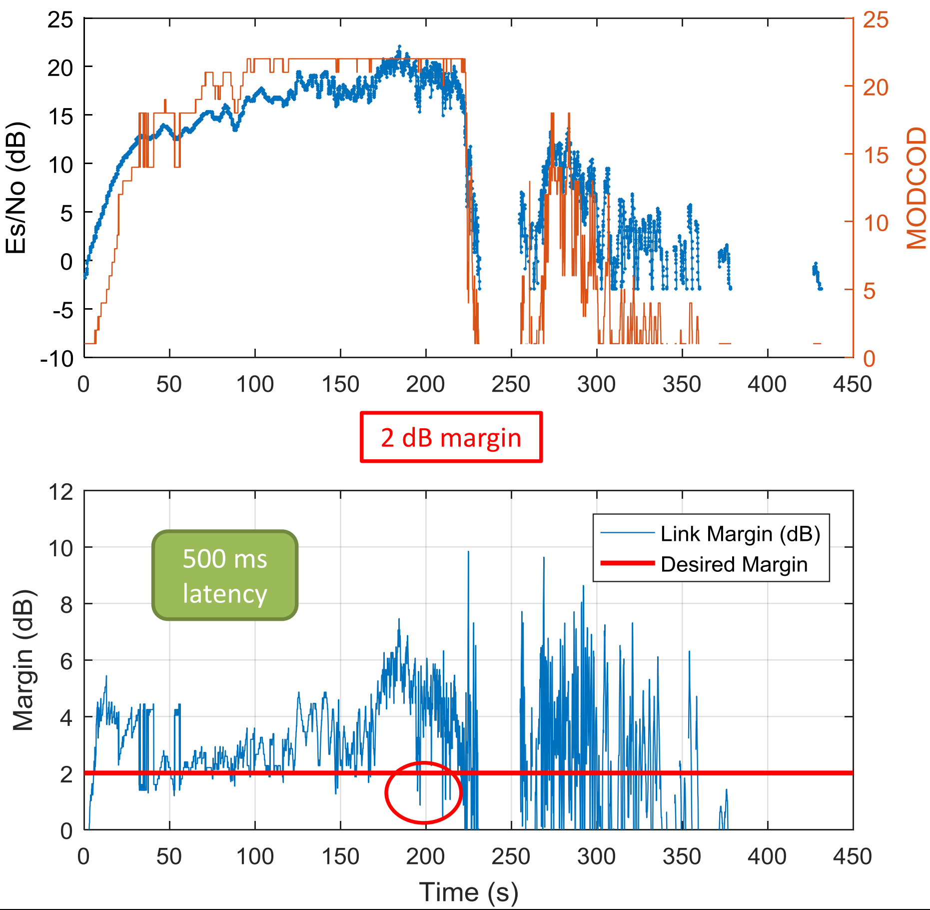




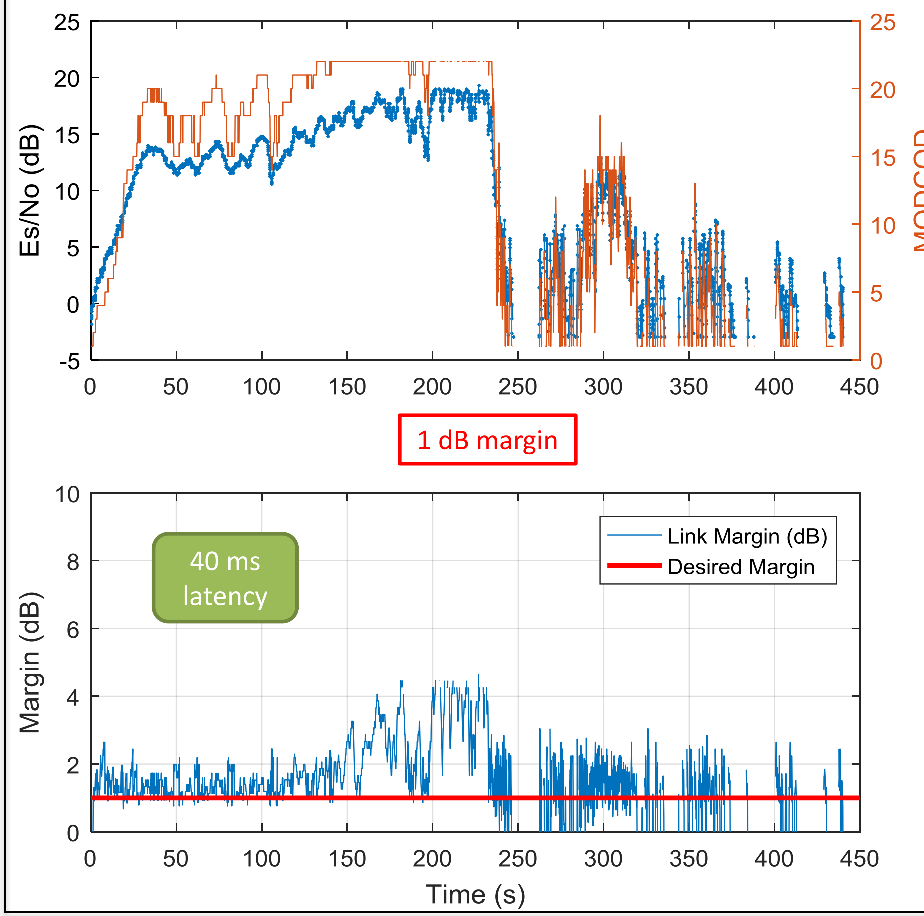
Event 2: 25 Apr 2016, 21:31 – 21:36

Round-Trip Delay (RTD) of ACM System

Initial RTD of 500ms:



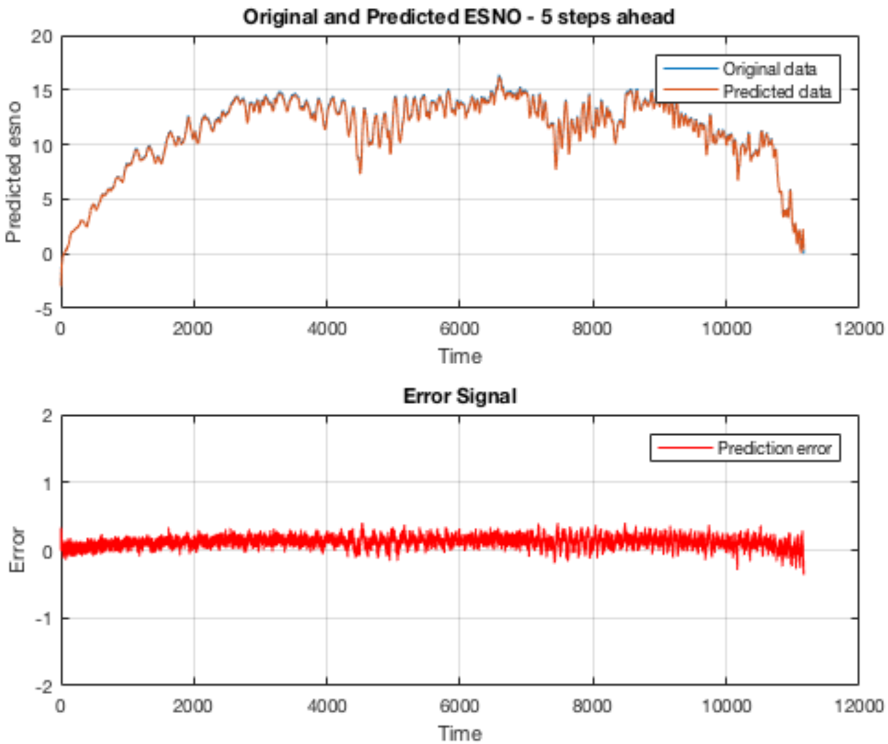
Final RTD of 40ms:



Intelligent Link Control

<u>Predictive / Learning Algorithm Developments (*in work*):</u>

- Simulation setup to evaluate performance of various algorithms for prediction and classification
- **Link predictor**: Replace simple decision with link predictor for intelligent link control
- **Link classifier**: Characterize link state, adjust link margin to match uncertainty



Multi-step Neural Network Prediction
5 step-ahead (t + 50 ms)

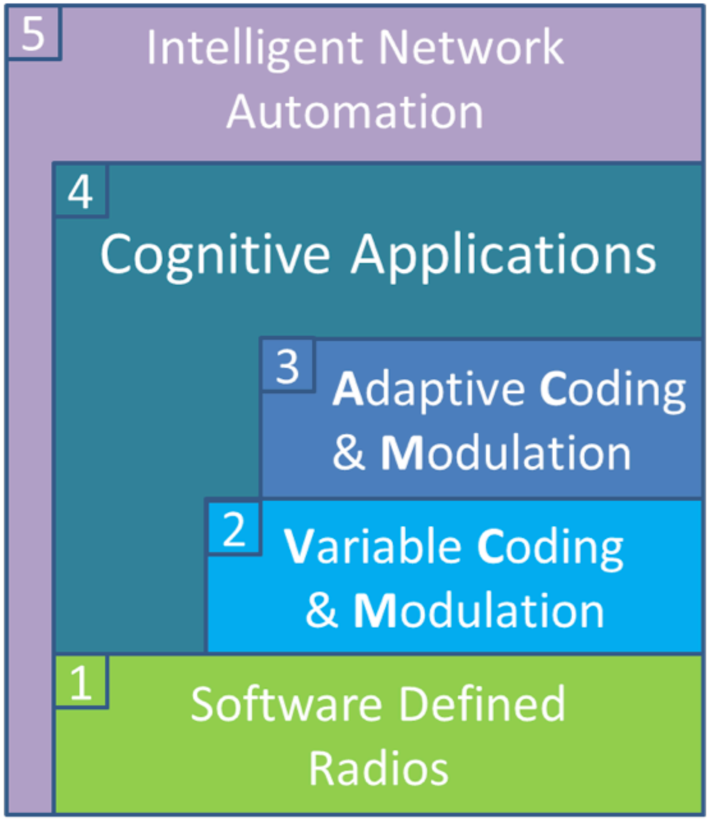
Cognitive algorithms being evaluated to improve performance

Conclusions

- DVB-S2 provides a reliable and widely-available mechanism for ACM
  - COTS DVB-S2 receivers were inexpensive and performed extremely well
  - Application to less dynamic links will have a more subtle improvement, but will still out-perform legacy NASA approaches
- ACM provides significant data throughput gains
  - 4.3dB improvement over legacy NASA CCM modes
  - 1.6dB improvement over VCM results
  - Performs within 0.25dB of the zero round-trip delay (ideal) case
- ACM significantly decreases operational overhead
  - Up-to-date event predictions were no longer needed
  - Ground software operated flight events autonomously

Future Work

- Adaptive point-to-point links are an important building block of intelligent communication systems
- Global mission needs should be managed at a system-wide level
  - Throughput optimization
  - Network scheduling
  - Spectrum sharing
- Now that configurable lower-layer protocols are in place, higher-layer cognitive applications can be developed and added for more optimal system performance



Additional Information

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Visit SCaN Testbed Online:
https://spaceflightsystems.grc.nasa.gov/sopo/scsmo/scan-testbed/

Visit STRS Online:
https://strs.grc.nasa.gov/

Image URL: http://deepspace.jpl.nasa.gov/about/website/

Presentation References

[1]J. A. Downey, D. J. Mortensen, M. A. Evans, N. S. Tollis, "Variable Coding and Modulation Experiment Using NASA's Space Communication and Navigation Testbed", NASA/TM-2016-219249, Jul. 2016.

[2]B. W. Welch and M. T. Piasecki, "Earth-Facing Antenna Characterization in Complex Ground Plane/Multipath Rich Environment", Antenna Measurement Techniques Association, Long Beach, CA, Nov. 2015.