Exploring Cognition using Software Defined Radios for NASA Missions

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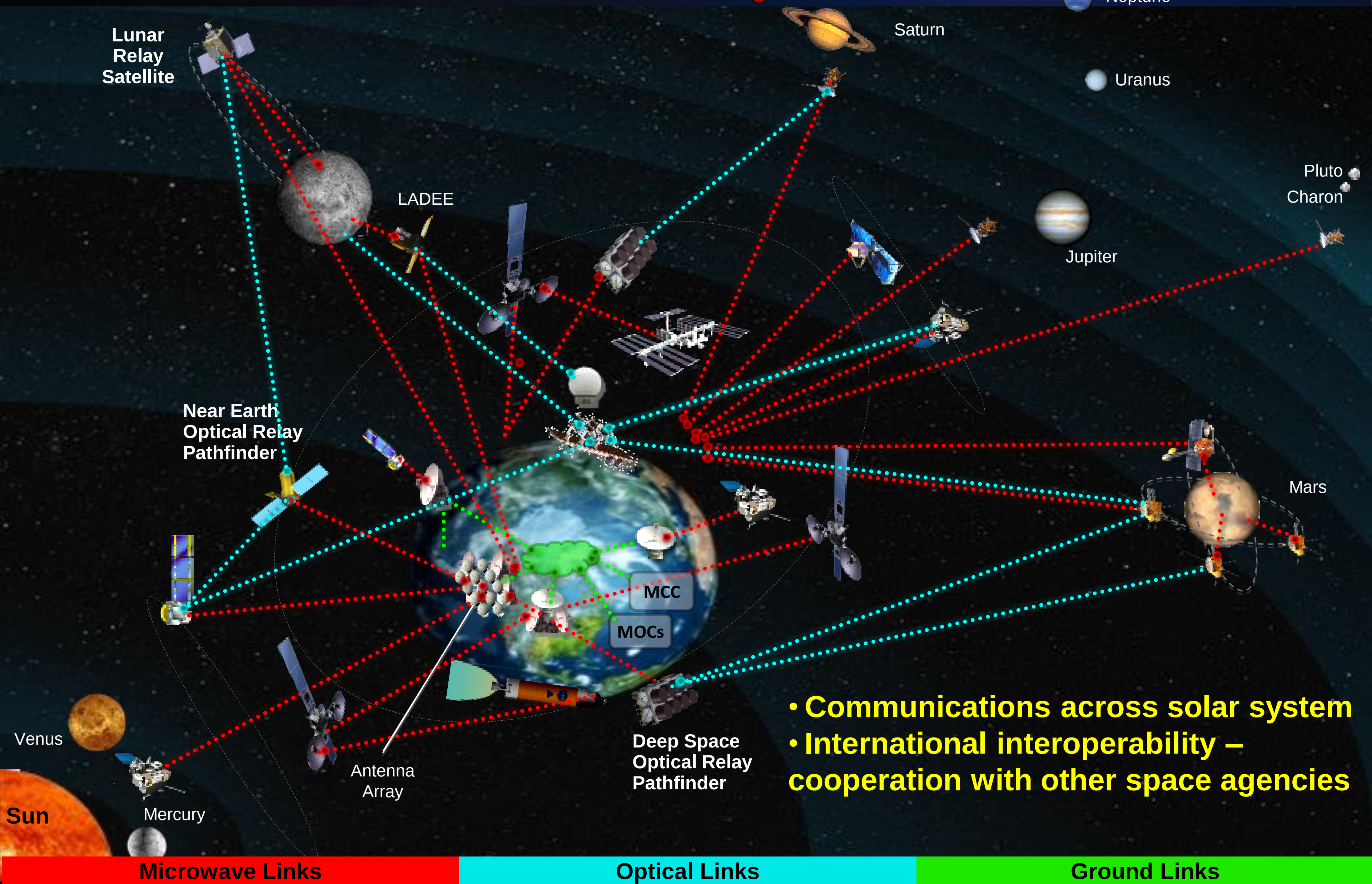
Future Space Communications

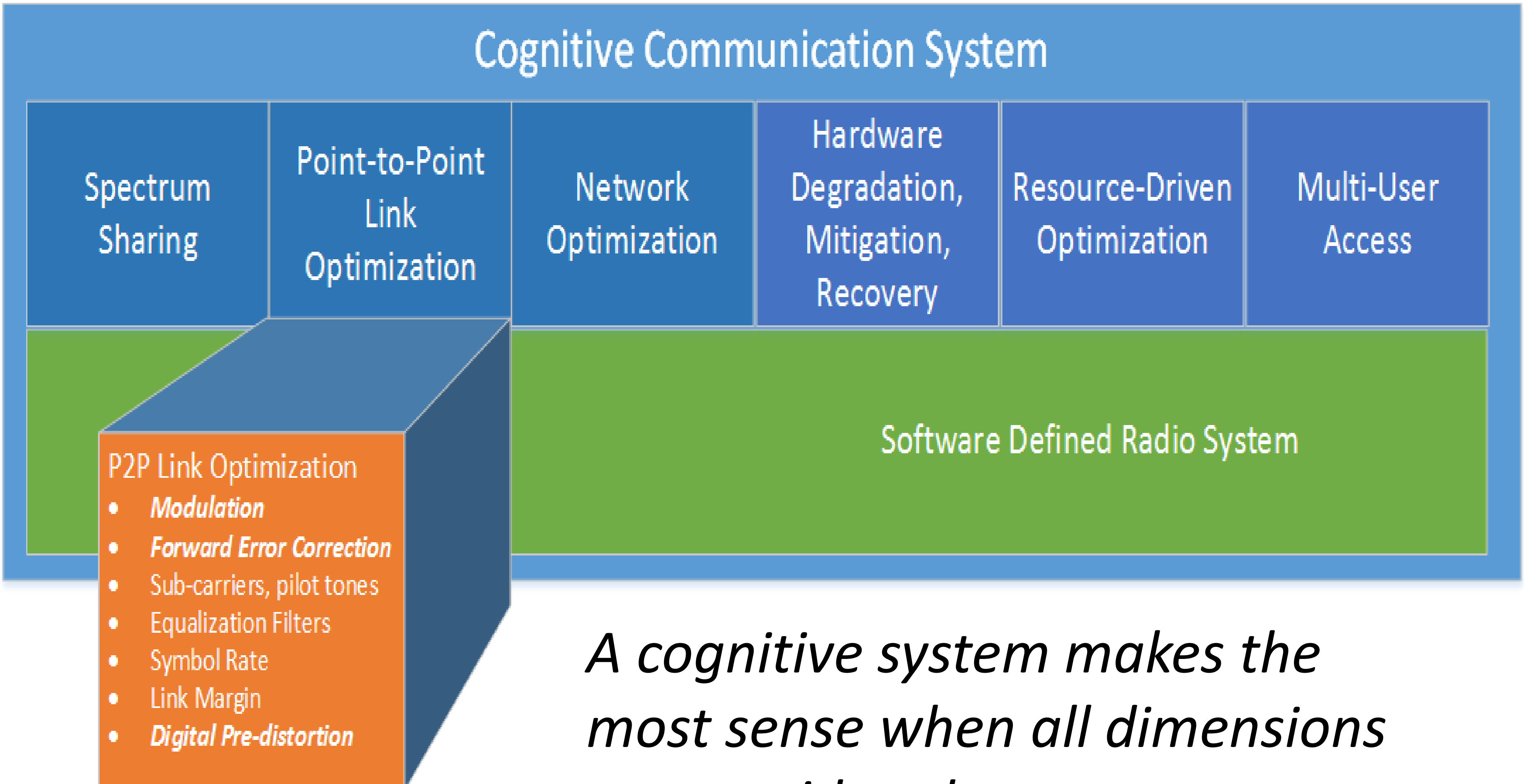


- Communications across solar system
- International interoperability – cooperation with other space agencies

Steps and Objectives for NASA Cognitive Communication Systems

5. **Intelligent Network Automation** — *Reduces operations complexity and cost.*
4. **Cognitive Applications** — *Maximizes data throughput, communications efficiency (BW, power, etc.), interference and other mitigations.*
3. **Adaptive Coding & Modulation** — *Improves point-to-point data throughput, reliability, and efficiency over VCM for non-deterministic environment changes.*
2. **Variable Coding & Modulation** — *Improves point-to-point data throughput and efficiency over fixed mode for deterministic environment changes.*
1. **Software Defined Radios** — *Flexible technology for communications and navigation*

Dimensions of Cognitive Communications *more than DSA*



A cognitive system makes the most sense when all dimensions are considered.

Adaptive/Cognitive Communications System Considerations

Adaptive/cognitive applications

- Node-to-node communications (local knowledge)
- Cognitive & adaptive techniques to better use link resources (margin/power/ spectrum) for data transfer (e.g. large volume)
- Self aware, able to respond to surroundings and link conditions

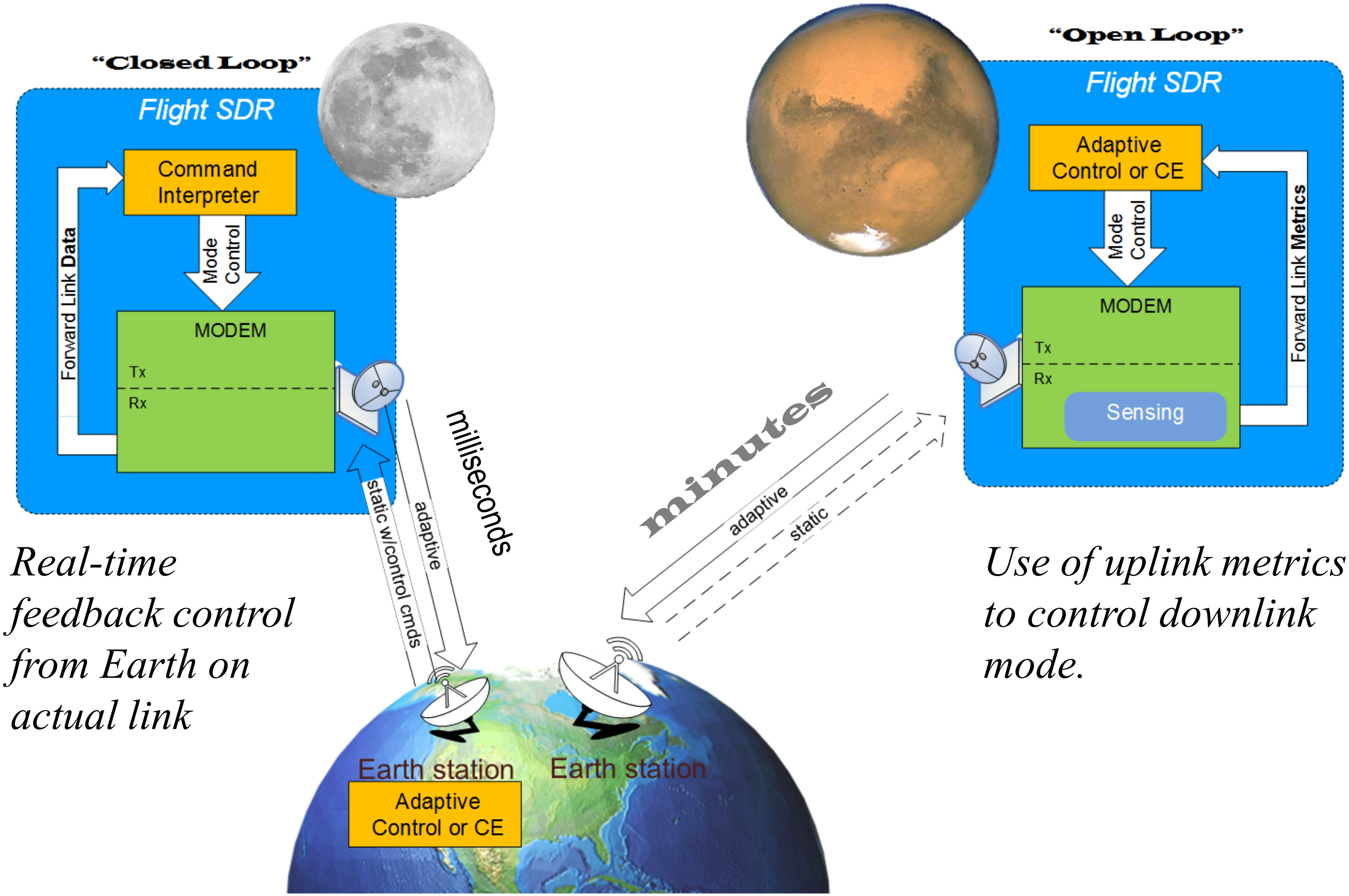
System wide knowledge and automation

- Ground control manages/monitors system assets for dynamic reconfiguration
- Architecture considerations for changing space system – inform network ops & MOC
- Automated service requests and usage, location sensitive information
- Event Manager grants requests according to other requests and priorities (hours, not weeks)
- Seamless connectivity among satellite relays and ground stations – use any available link

Internetworking (reliable data transport)

- Disruptive tolerant networking (DTN) overlay of adaptive/cognitive system
- DTN protocol changes to accommodate data rate and link changes (multi-node)
- Anytime, anywhere, any network connectivity

Distance Matters



Real-time feedback control from Earth on actual link

Use of uplink metrics to control downlink mode.

Point-to-Point VCM/ACM Example
DVB-S2 Compatible Waveform

- Transmit waveform targeted for S-band SDR
- Compatible with the DVB-S2 standard V1.3.1
- Operates up to 6.16 Msym/s
- Up to 27.3 Mbps user data
- Direct-to-earth link band limited to 5 MHz (4.55 Msym/s, 20 Mbps)

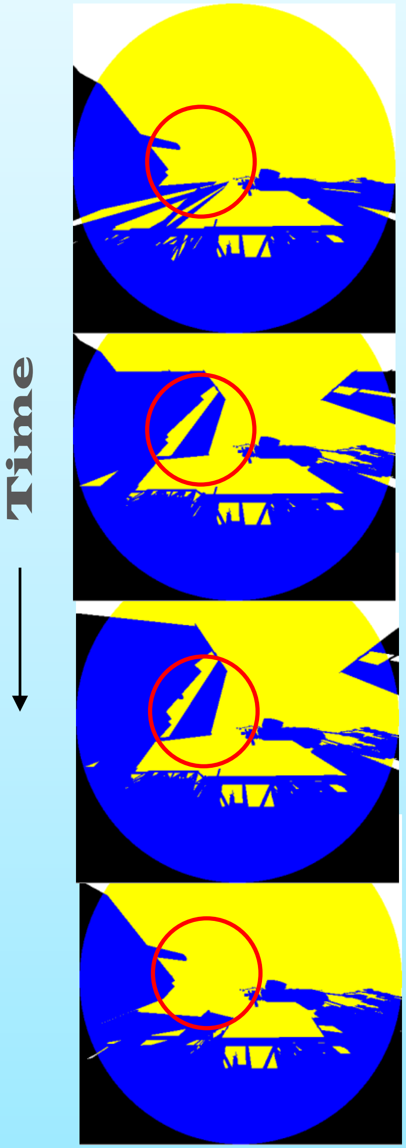
Transmit Filters: SRRC, α = 0.2, 0.25, 0.35, span = 12 symbols

Framing: CCSDS AOS

Utilization: 50% of Virtex-2 XC2V3000

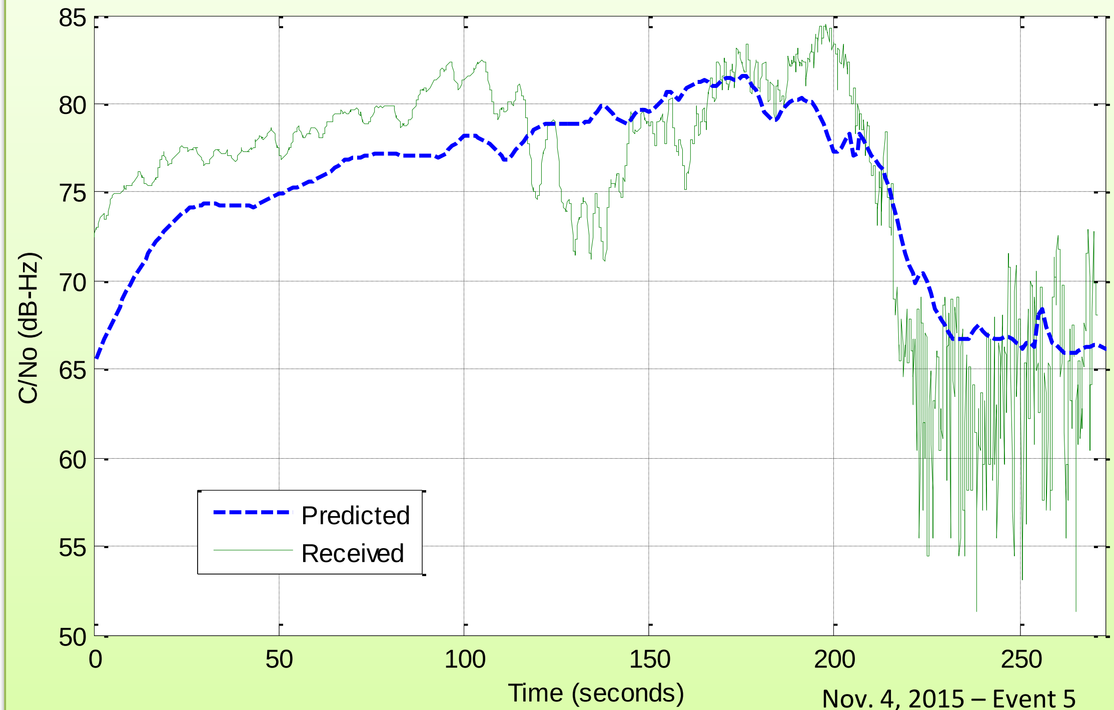
Mode	MODCOD	Mode	MODCOD
QPSK 1/4	1	16APSK 2/3	18
QPSK 1/3	2	16APSK 3/4	19
QPSK 2/5	3	16APSK 4/5	20
QPSK 1/2	4	16APSK 5/6	21
QPSK 3/5	5	16APSK 8/9	22
QPSK 2/3	6	32APSK 3/4	24
QPSK 3/4	7	32APSK 4/5	25
QPSK 4/5	8	32APSK 5/6	26
QPSK 5/6	9	32APSK 8/9	27
QPSK 8/9	10		
8PSK 3/5	12		
8PSK 2/3	13		
8PSK 3/4	14		
8PSK 5/6	15		
8PSK 8/9	16		

ISS direct-to-earth link environment



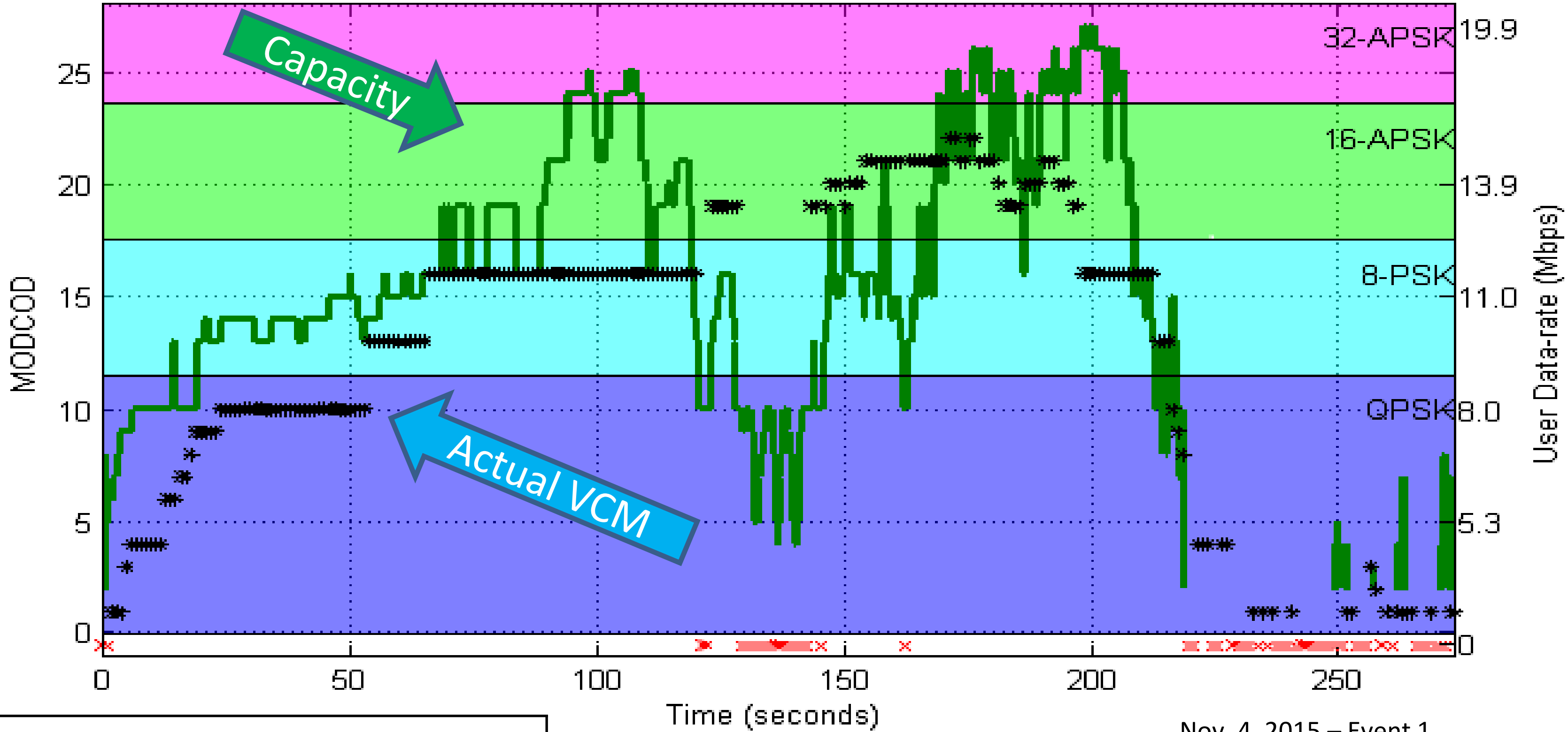
Fixed antenna view from SCaN Testbed to GRC Ground Station showing solar panel obscuration.

Graphics Courtesy of Virginia Tech



Dynamic link difficult to model completely –appropriate scenario for automated adaptive approach.

DVB-S2 Direct-to-Earth VCM Testing Results



Nov. 4, 2015 – Event 1

User Data Throughput	
VCM actual vs	Gain/Loss
NASA Legacy	3.71 dB
Prediction	-0.59 dB
Capacity	-0.80 dB

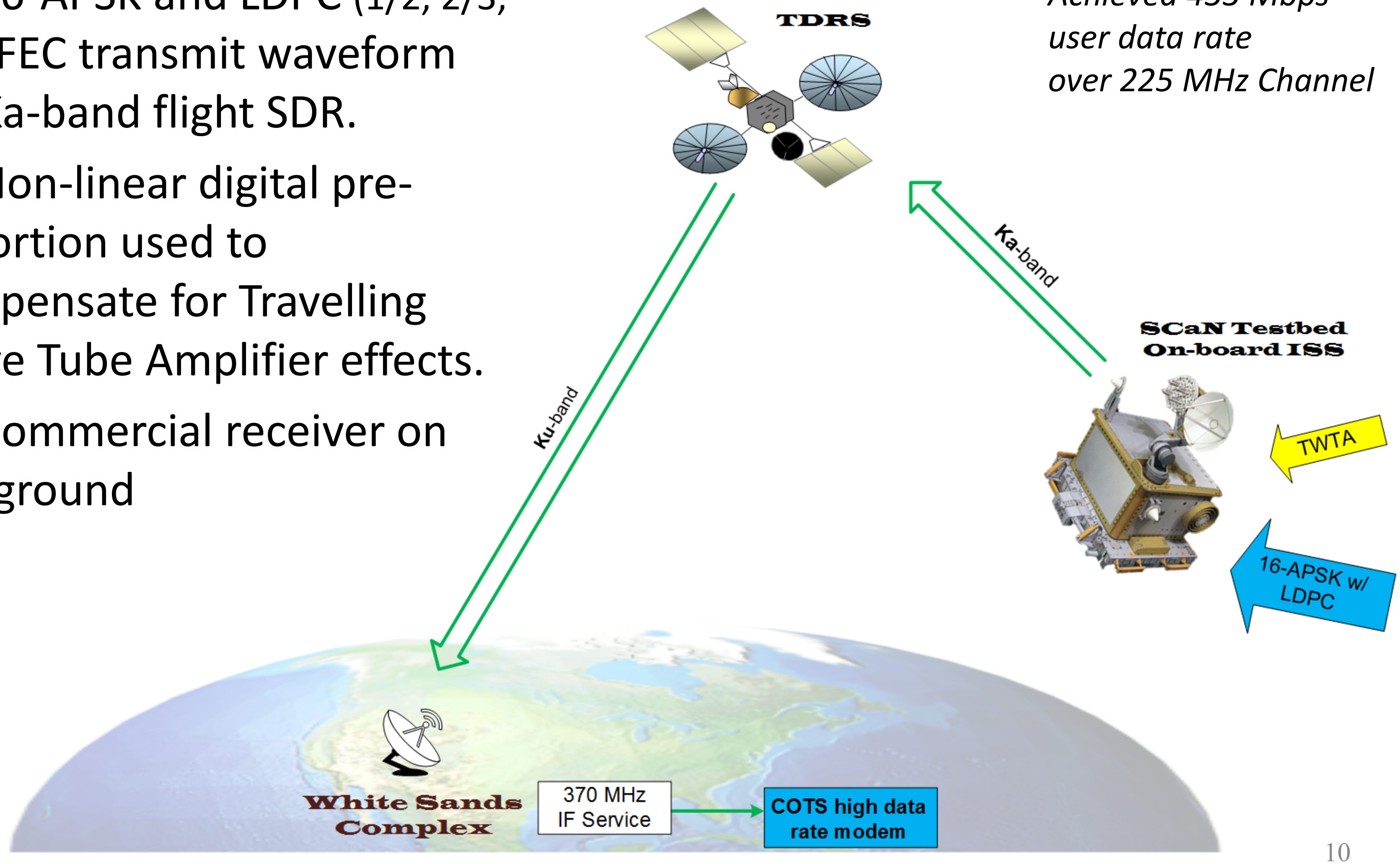
VCM yields significant increase in user data throughput over constant modulation and coding.

ACM will improve performance further towards capacity.

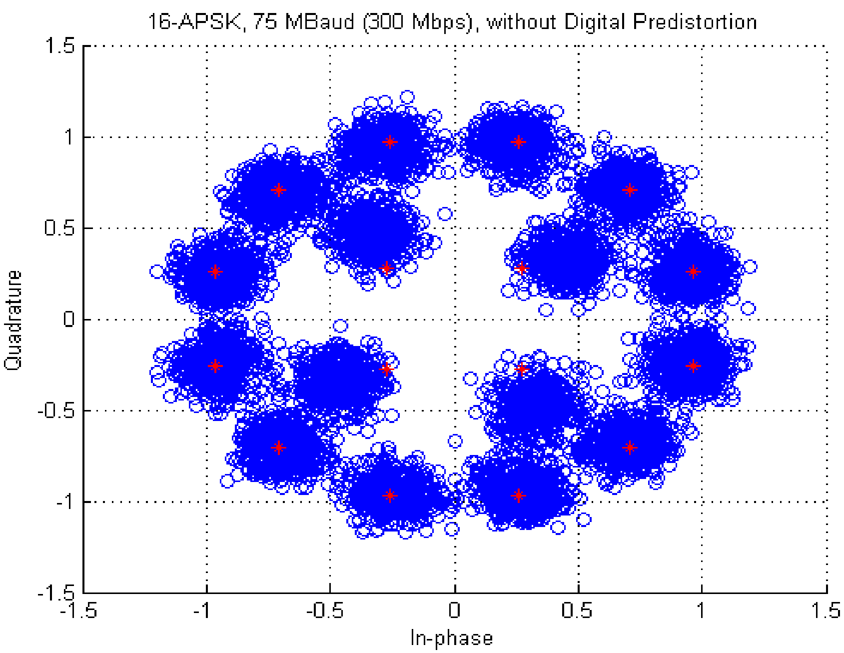
Point-to-Point Optimization Example
Digital Pre-distortion On-orbit Test

- 16-APSK and LDPC (1/2, 2/3, 7/8) FEC transmit waveform on Ka-band flight SDR.
- Non-linear digital pre-distortion used to compensate for Travelling Wave Tube Amplifier effects.
- Commercial receiver on the ground

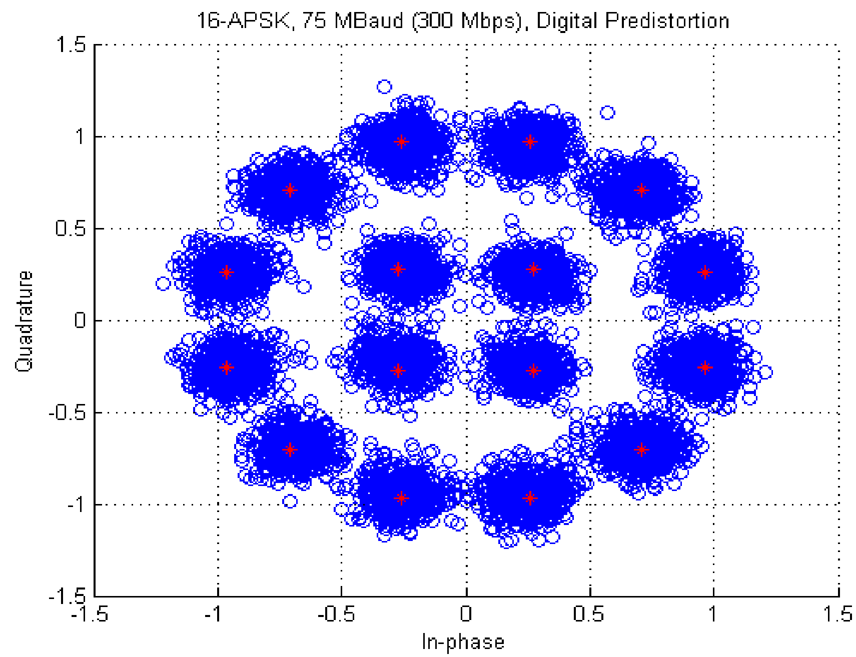
Achieved 433 Mbps user data rate over 225 MHz Channel



Point-to-Point Optimization Example
Digital Pre-distortion Results



DPD off EVM = 34%



DPD on EVM = 14%

- 16-APSK digital pre-distortion module: gain and phase adjustment of inner and outer rings to account for non-linearity
- Enables operation near saturation point of amplifier, and improves BER performance
- Plans to make this a dynamic adaptation with full duplex feedback

Adaptive/Cognitive University Experiments

Virginia Tech - *Adaptive Modulation*

- Applying to direct-to-earth S-band uplink
- Using six PSK and QAM modulation schemes
- New waveform apps for SCaN Testbed; USRP development for ground systems
- Simulations show when shadowing from solar panels occur

Worchester Polytechnic and **Penn State -** *Adaptive Link Layer Protocol*

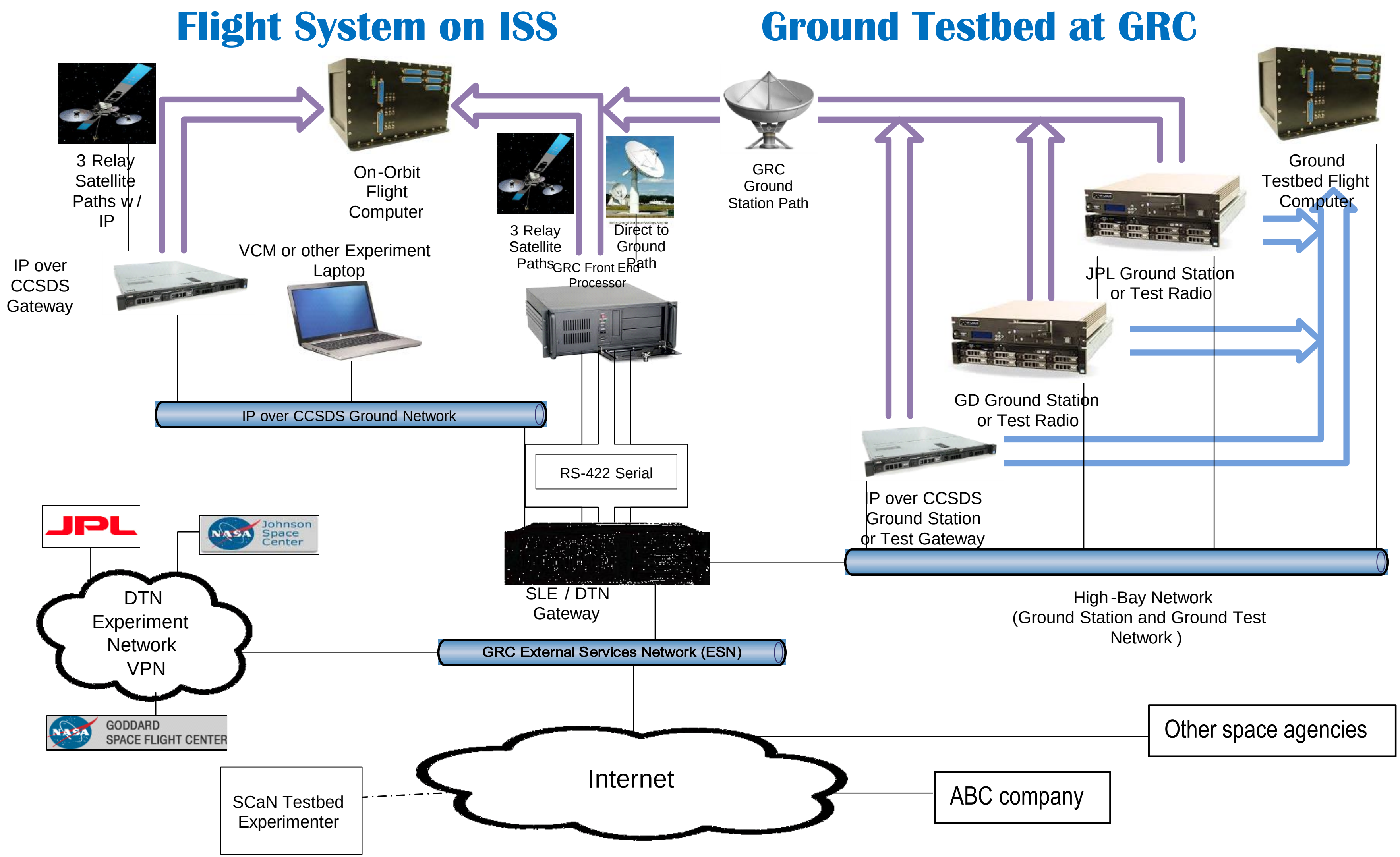
Atmospheric & Space Weather Impairments Research

- Time/temperature varying effects of ionosphere at Ka/S-band
- Multipath propagation of scintillated signals
- Mapping of effects into distinct states

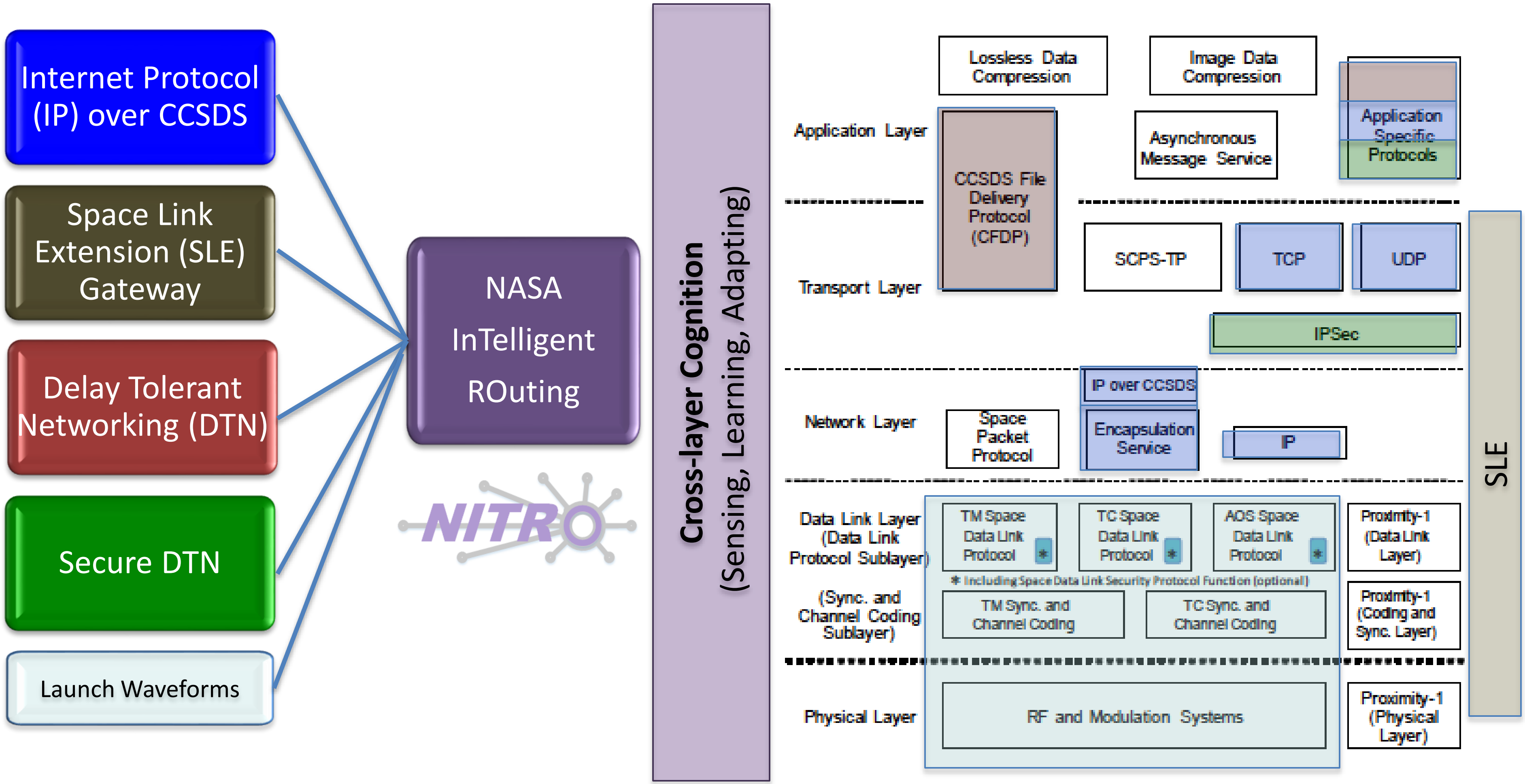
Cognitive algorithms

- Machine learning: Neural networks, Reinforcement learning

SCaN Testbed Ground Network



Evolution to Intelligent Routing



End-to-end Data Exchange is:

Adaptive, Autonomous, Cross-layer Connecting, Secure, Scalable.

For more information

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visit SCaN Testbed on-line:

http://spaceflightsystems.grc.nasa.gov/SOPO/SCO/SCaNTestbed