National Aeronautics and Space Administration

The Space Communications and Navigation Testbed aboard International Space Station: Seven Years of Space-based Reconfigurable Software Defined Communications, Navigation, and Networking

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July 2019

ISS Research and Development Conference

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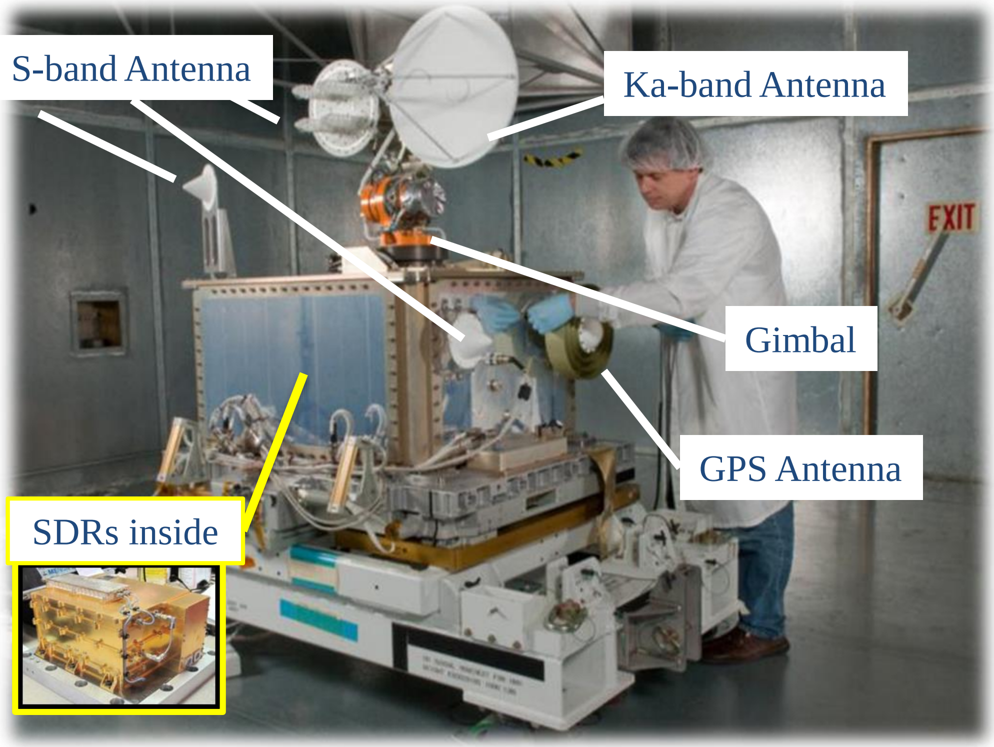
Sponsored by the Space Communication and Navigation Program

Outline

- ❑ **Mission Description**
- ❑ **Accomplishments, Infusion, and Commercialization**
- ❑ **Experiment Highlights**
- ❑ **Acknowledgements**

SCaN Testbed – Software Defined Radio-based Communication System

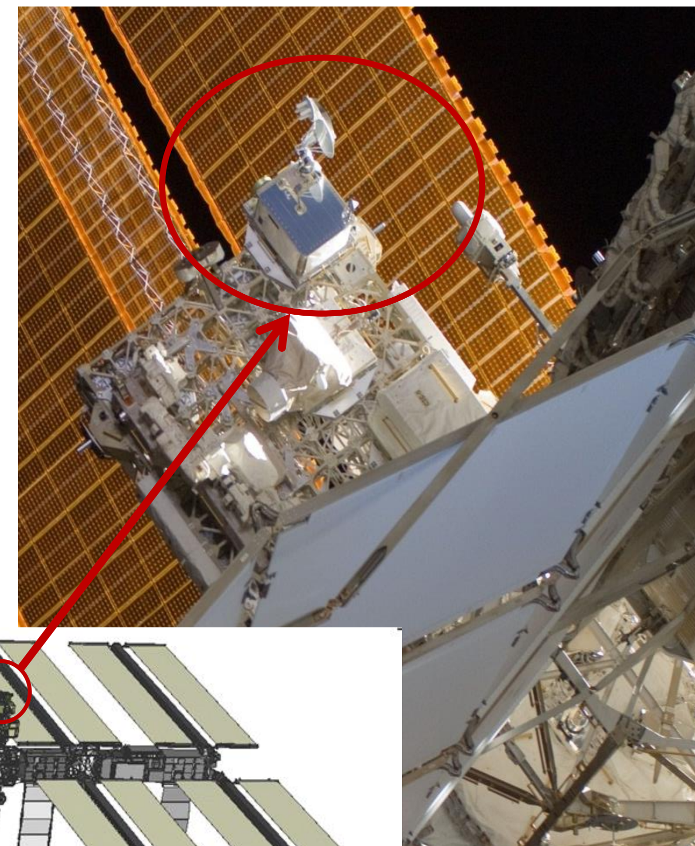


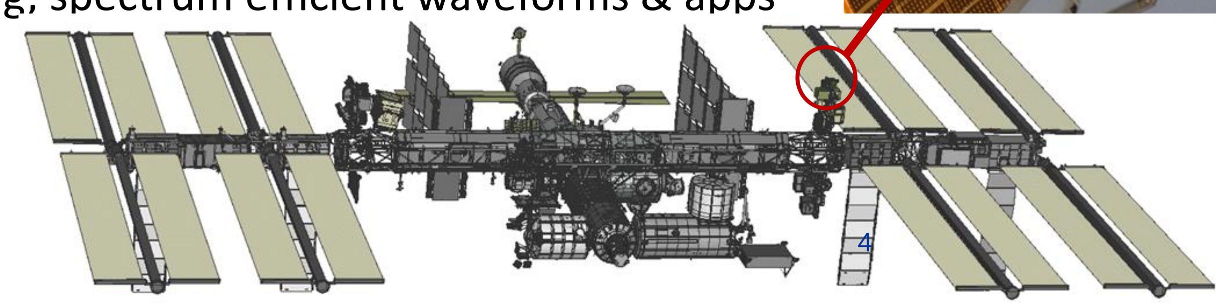
- **SDRs provide unprecedented flexibility that allows communications functions in software to be updated in development or flight**
- **Software defined functionality enables standard radios to be tailored for specific missions with reusable software**
  - Like different PCs running Apps on an operating system, standardization enables different radio platforms to run common, reusable software across many missions
  - Cost reductions possible with common architecture, reusable software and risk avoidance
- **Software Defined Radios were the "Instruments" of the SCaN Testbed**

- **SDRs - Two S-band SDRs (one with GPS), Ka-band SDR**
- **RF - Ka-band TWTA, S-band switch network**
- **Antennas - Two low gain S-band antennas, L-band GPS antenna, Medium gain S-band and Ka-band antenna on antenna pointing subsystem.**
- **Antenna pointing system - Two gimbals, Control electronics**
- **Flight Computer/Avionics**

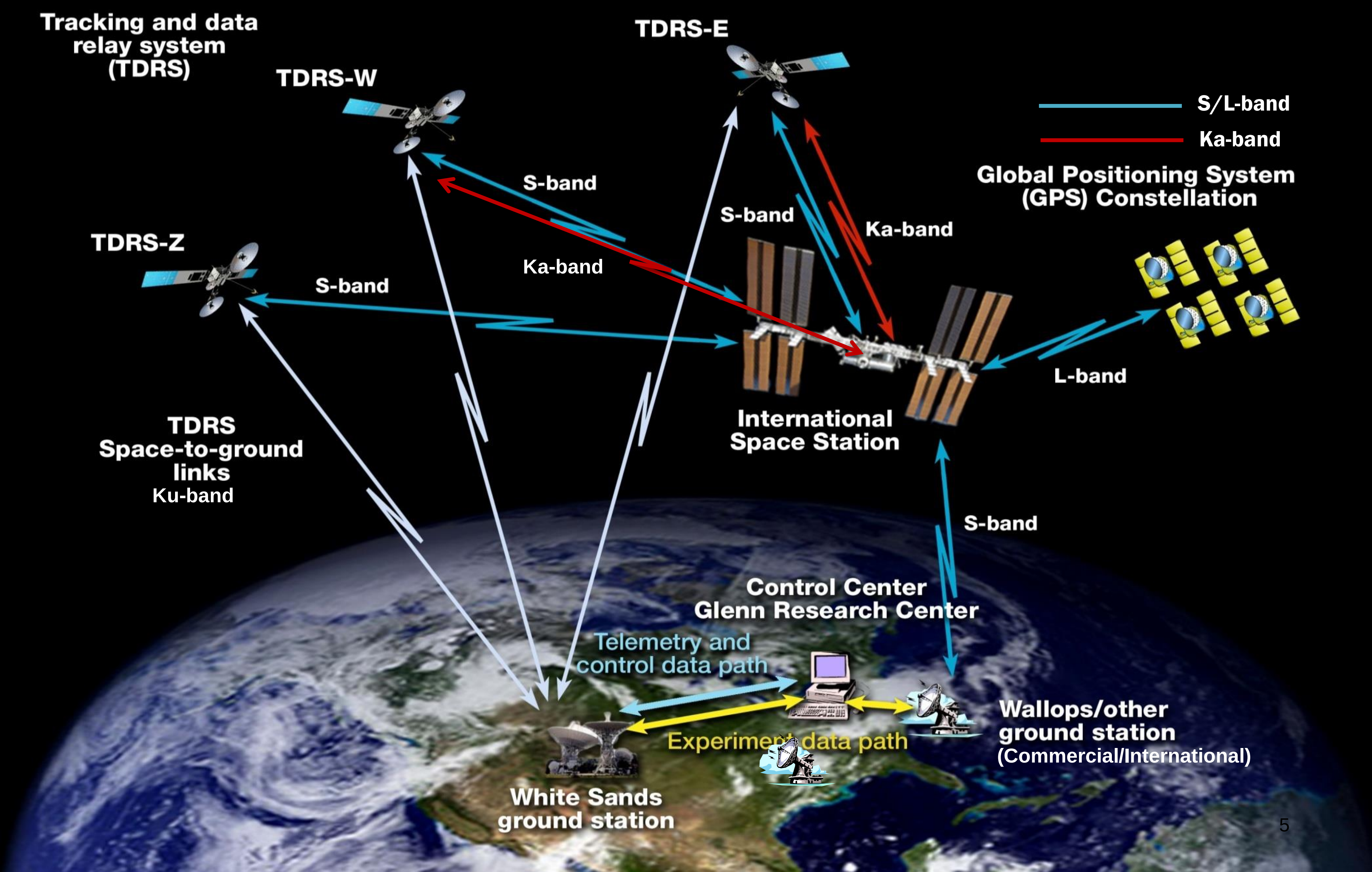
SCAN Testbed Mission Objectives – all achieved!

- **Advanced Software Defined Radio (SDR) technologies and infrastructure for future SCaN architecture and NASA Missions**
  - SDRs now routinely considered for space missions, changed culture of SDRs
  - SDR space use included verification, reconfiguration, ops, and new software aspects
- **Conducted Experiment's Program**
  - Over 25 organizations participated in portfolio of experiments
  - Built waveforms and educated app developers
  - Operations from July 2012- June 2019
- **Validated for Future Missions**
  - Capabilities: S-band, Ka-band, GPS
  - Technologies: communication, navigation, networking, spectrum efficient waveforms & apps





SCAN Testbed System Architecture



SDR Research & Technology On-orbit Accomplishment Summary

- **Over 4000 hours of SDR operations in space**
- **Over 880 SDR reconfigurations. Demonstrated new software verification and new capability added on-orbit**
- **Operated NASA's first Ka-band mission with TDRSS. Many lessons learned for both project team and NASA Ka-band system. Helped validate newest TDRS (i.e., K, L, M)**
- **Received GPS carrier signals; first civilian reception of new L5 signals in space. Conducted tests with the newest GPS satellites.**
  - Supported Air Force's GPS satellite and civilian message validation tests
- **STRS-compliant SDRs successfully implemented and operated in space - NASA's new standard for SDRs, NASA-STD-4009A**
  - Contributed software to STRS waveform application repository
  - STRS integrated into NASA's Core Flight System (cFS)

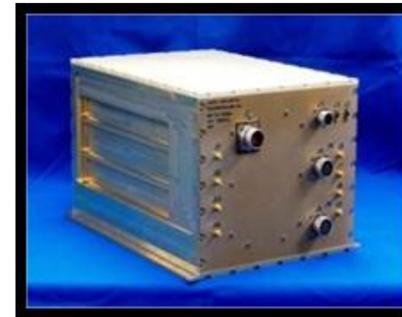
Demonstration in space is key to TRL advancement

SCaN Testbed & STRS Technology Infusion

- Experiments advanced different aspects of high rate communications, networking, and GPS-based navigation technology- results and lessons learned shared with missions and technology programs
- Heavily used for validation of future SCaN relay services and to investigate new concepts for other users (e.g. ISS) using the TDRSS 225 MHz service. SCaN Testbed flexible to emulate all SCaN services
- Flight validate CCSDS protocols using end-to-end system as required for final "Blue Book" protocol/standards prototypes. SCaN Testbed implementing many CCSDS standards
- Providing flight DTN implementation corrections and new capabilities and secure DTN upgrades to ION NASA Baseline (open source DTN source for missions)
- Experiments demonstrate cognitive control of flight system SDRs
- Future Mars radio (Universal Space Transceiver) to be STRS compliant.
- Multiple commercial SDR product lines have STRS compliant SDRs available to NASA missions.

SCaN Testbed Technology Commercialization Highlight

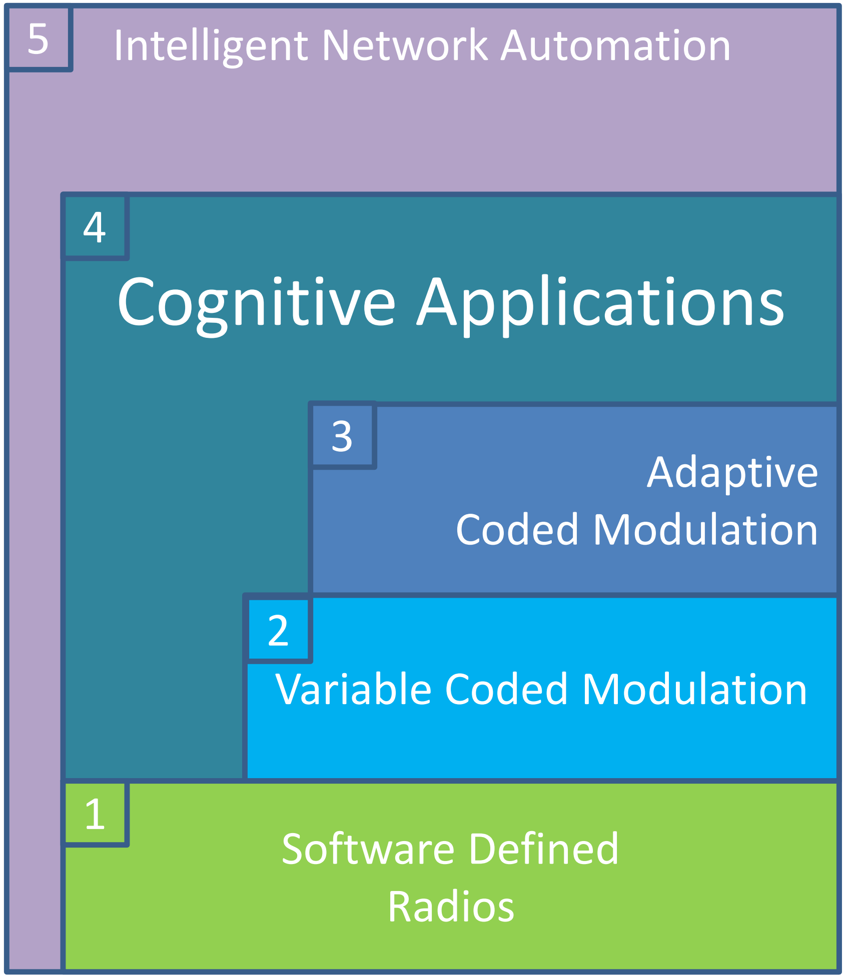
- NASA GRC and Harris were inducted into the Space Foundation's Space Technology Hall of Fame for the Ka-band SDR in March 2019.
  - NASA and Harris developed the SDR in a 50/50 cost-share partnership
- SCaN Testbed SDR evolved into a reconfigurable multimission payload called Harris AppSTAR™ and has been deployed on a variety of satellites:
  - Hosted platform for the Iridium NEXT satellites for Aireon's Automatic Dependent Surveillance-Broadcast (ADS-B) payload, the world's first space-based global air traffic surveillance service
  - Payload that enables the world's lowest-latency ship tracking service, exactEarth's exactViewRT,
  - Adapted for small satellites and on-orbit demonstration of reprogramming capability for the company's own 6U CubeSat.



"The Space Technology Hall of Fame was created in 1988 to recognize life-changing technologies emerging from global space programs; honor the scientists, engineers and innovators responsible; and communicate to the public the importance of these technologies as a return on investment in space exploration."
https://www.spacefoundation.org/what-we-do/space-technology-hall-fame

Experiment Highlights

Approach for NASA Cognitive Communication Systems



Reduces operations complexity and cost.

Maximizes data throughput, communications efficiency (BW, power, etc.), interference and other mitigations.

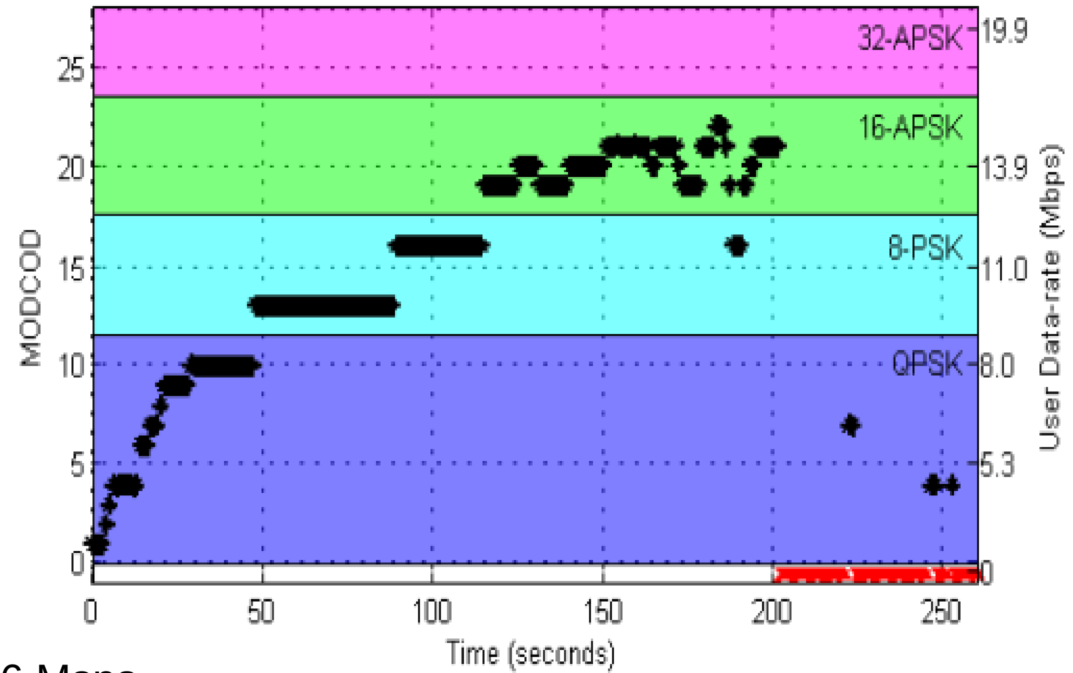
Improves point-to-point data throughput, reliability, and efficiency over VCM for non-deterministic environment changes.

Improves point-to-point data throughput and efficiency over fixed mode for deterministic environment changes.

Flexible technology for communications and navigation

High Rate Bandwidth Efficient & Adaptive Waveforms

- **High BW & Efficient operated ~600 Mbps link over 225 MHz channel**
  - OQPSK, and LDPC rate 7/8 and rate 1/2
  - Significant improvement over 100 Mbps launch waveform with ~2x improvement in spectral efficiency.



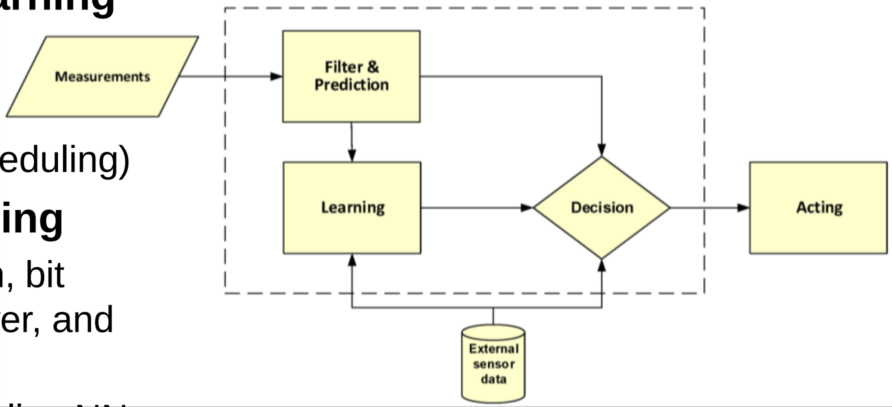
- **Adaptive DVB-S2 waveform**
  - Modulation: GMSK, BPSK, OQPSK, 4/8/16-PSK, 16-QAM, 16-APSK, 32-APSK
  - Data Rate: Fully adjustable up to 800 Mbps,
  - Pulse-shape Filtering, Error correcting codes

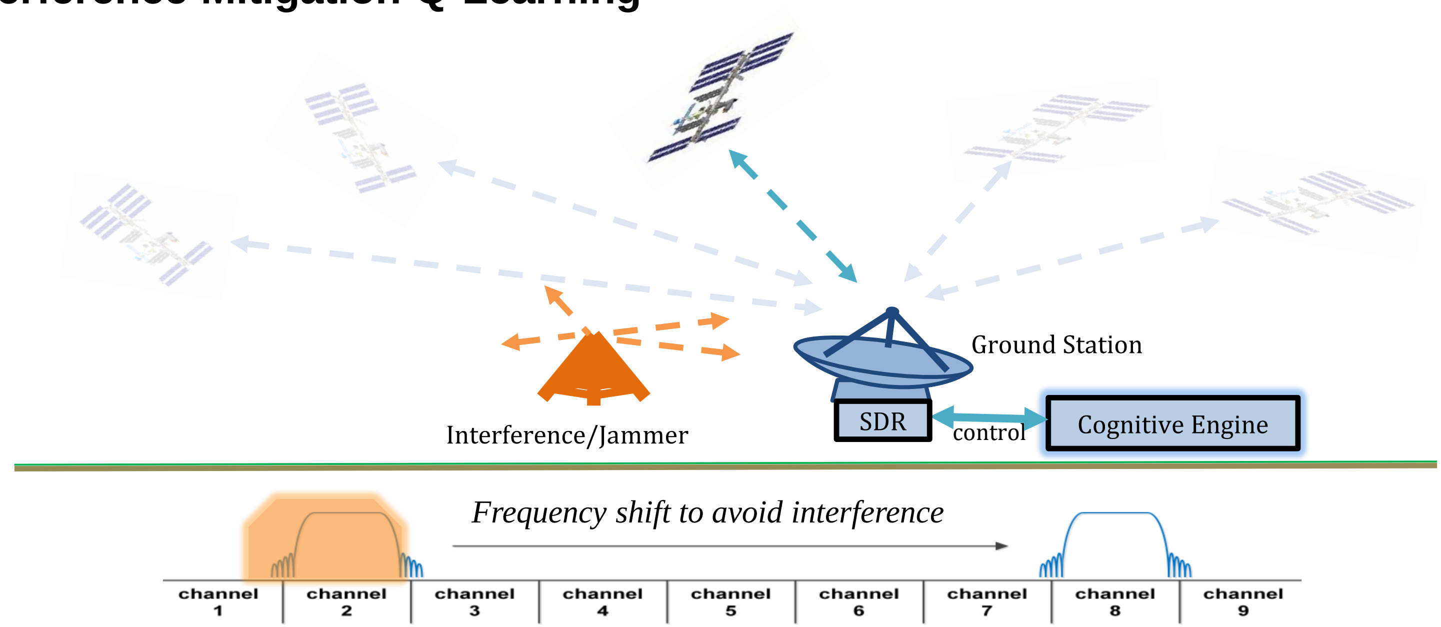
- **DVB-S2 Performance**
  - S-band symbol rate: 100 ksps to 6 Msps
  - Ka-band symbol rate: up to ~200 Msps
  - Variable (predictive performance) yielded 2.7 dB improvement
  - Adaptive coding/modulation (VCM/ACM): feedback from receiver to transmitter yielded 4.4 dB improvement

Cognitive Link Optimization

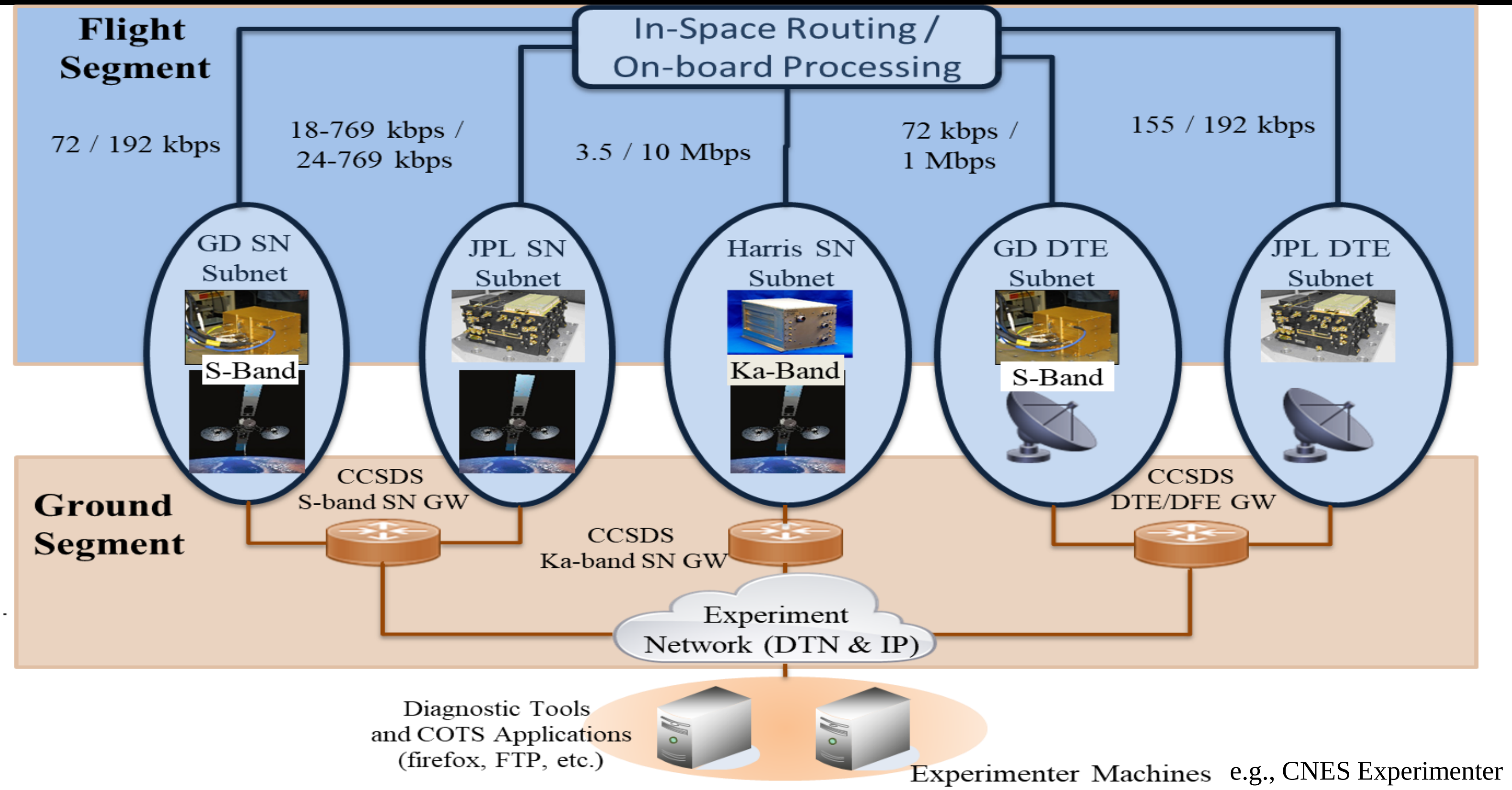
- **Cognitive/Artificial Intelligence/Machine Learning**
  - Links, node-to-node
  - Network based intelligent routing
  - System wide efficiency and operations (e.g., scheduling)
- **Links: Multi-Objective Reinforcement Learning**
  - Optimize configuration for throughput, bandwidth, bit error rate (performance), spectral efficiency, power, and power efficiency
  - Reinforcement Learning Neural Network with off-line NN for training, to mitigate link disruption during exploration
- **Links: Interference Mitigation Q-Learning**

cognitive algorithm – WPI/PSU





SCaN Testbed IP and DTN Network (IP over CCSDS)

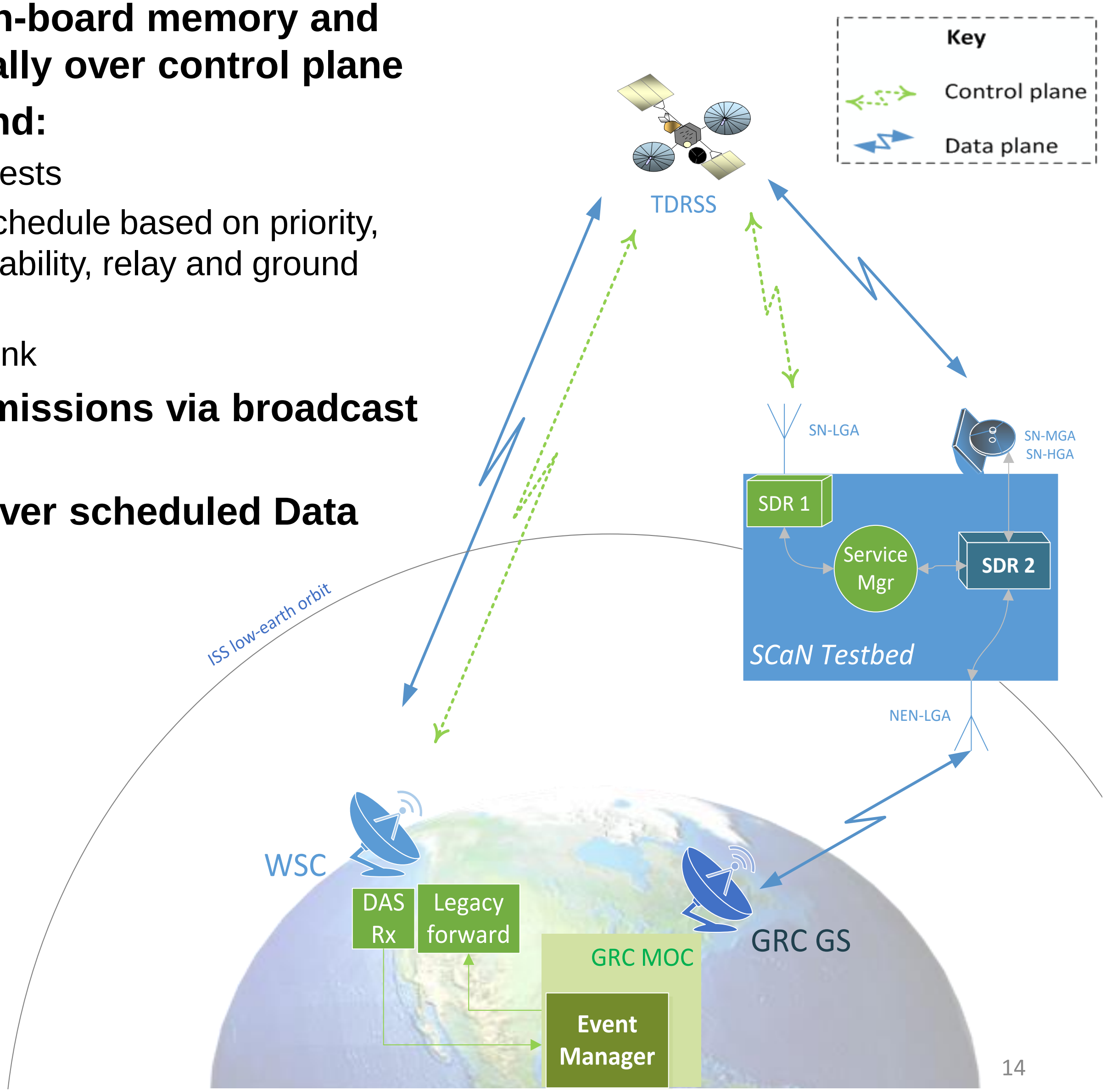


- **Extensive multi-node, multi-path, in-space, IP/DTN network**
  - Three satellite paths, two direct to ground paths
- **IP routing and DTN are basic elements of the future SCaN Network**
- **Implemented IP stack in the flight computer (VxWorks, PPC) to each radio and DTN ION from open source SourceForge website**
- **DTN interoperability validated with CNES, Toulouse, France.**

Automated Schedule Request System

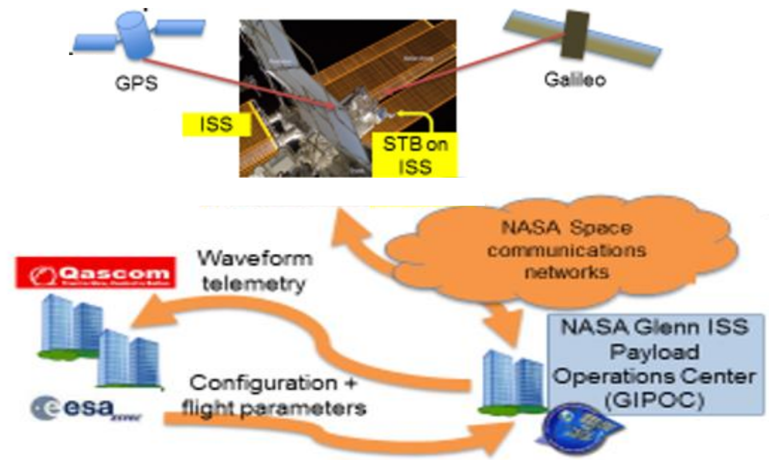
- **User spacecraft monitors on-board memory and requests service automatically over control plane**
- **Event Manager on the ground:**
  - Responds to all mission requests
  - Coordinates near real-time schedule based on priority, throughput, user satellite capability, relay and ground station availability
  - Selects and schedules best link
- **Schedule message sent to missions via broadcast service over Control Plane**
- **User satellite returns data over scheduled Data Plane network access**

- **Flight demo – August 2017**
  - 17 service requests granted and executed
  - >200 minutes of autonomous service
  - Scheduled with as little as **15 minutes lead** time **instead of 3 weeks**.

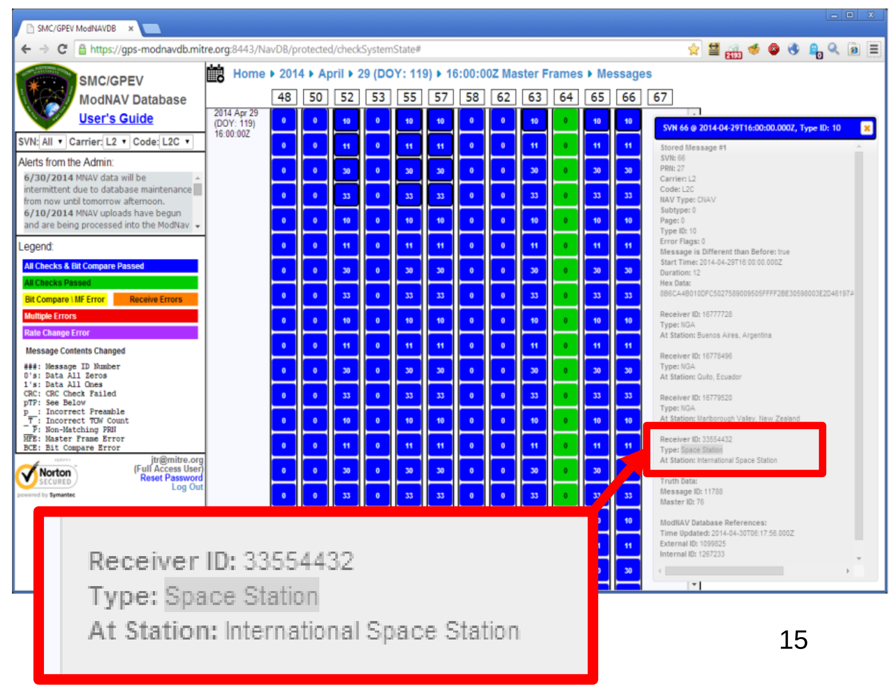


Navigation Accomplishments

- **GARISS – Galileo and GPS Receiver for the International Space Station**
  - Partnership between NASA and ESA to develop a navigation waveform for precise orbit determination using GPS L5 and Galileo E5A signals
  - Successfully demonstrated over 90% combined observability, versus GPS-only (20%) and Galileo-only (40%) solutions.



- **GPS Civilian Navigation Message (CNAV) Testing**
  - Only civilian space user to support the US Air Force CNAV test campaigns in 2013 and 2014.
  - Provided valuable in-space monitoring of 169 satellite-hours of CNAV broadcasts covering all GPS satellites involved in the test campaign



Summary

- **SCaN Testbed mission successfully completed!**

- **Numerous technical publications available on the various experiments conducted**

- **SDR communications, network, and navigation technology:**
  - Advanced; operation understood, risks mitigated
  - Infused in NASA missions
  - Infused in commercial products and services

Acknowledgements & Contributions

- **NASA HQ Sponsor: Space Communications and Navigation (SCaN) Program**
- **GRC, GSFC, JPL, JSC, MSFC**
- **Space Network (SN), Near Earth Network (NEN)**
- **White Sands Complex (WSC)**
- **ISS Program Office**
- **Payload Operations Integration Center (POIC)**
- **Industry Partners**
  - General Dynamics
  - Harris
- **Experiment cited in the presentation**
  - Thomas Kacpura, James Lux, Joseph Downey, Michael Evans, David Brooks, Wesley Eddy, Alexander Wyglinski, Paulo Ferreira, Sven Belin, Timothy Hackett, Dean Schrage, Larry Vincent, Gus Gemelas, Christopher Roberts, David Israel, Mick Koch, Nicholas Tollis, Obed Sands, Bryan Welch, Maria Piasecki, Louis Handler, Bluecom, ESA, CNES ….
- **Operations**
  - Beth Curtis, Helen Brown, Daniel McGiffin, Alan Rybar, Jason Murray, Raymond Pavlik, ….
- **…and more**

Many Organizations and Individuals Involved in SCaN Testbed Experiments & Operations

For more information

https://www1.grc.nasa.gov/space/scan/acs/scan-testbed/

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