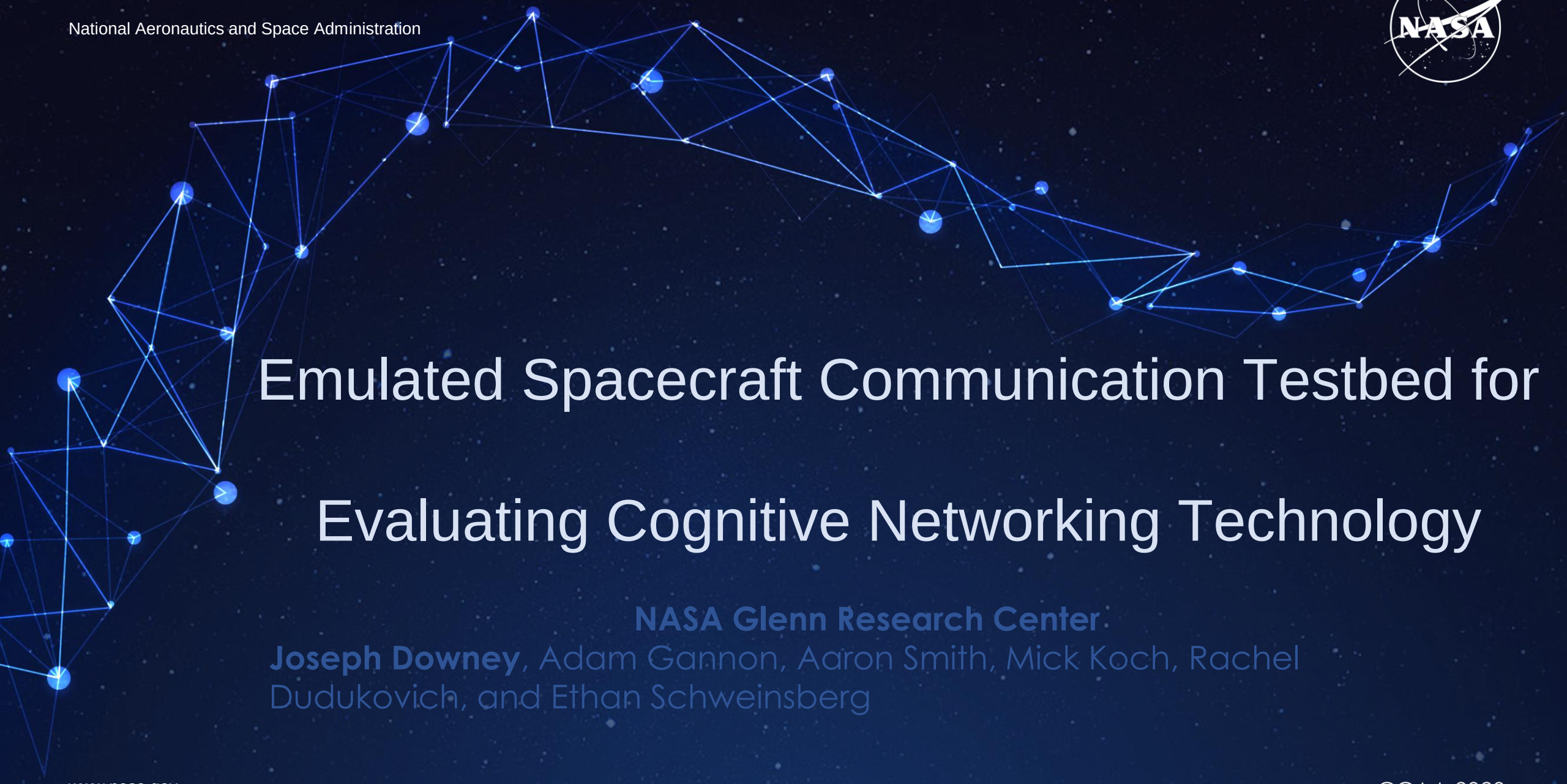
National Aeronautics and Space Administration



Emulated Spacecraft Communication Testbed for Evaluating Cognitive Networking Technology

NASA Glenn Research Center

Joseph Downey, Adam Gannon, Aaron Smith, Mick Koch, Rachel Dudukovich, and Ethan Schweinsberg

AGENDA

- Introduction / Motivation
- Testbed Overview
- Scenario Definition
- Networking Dataflow / Metrics
- End-to-End Testing
- Conclusions

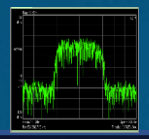
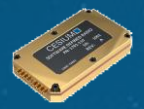
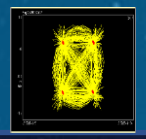
INTRODUCTION

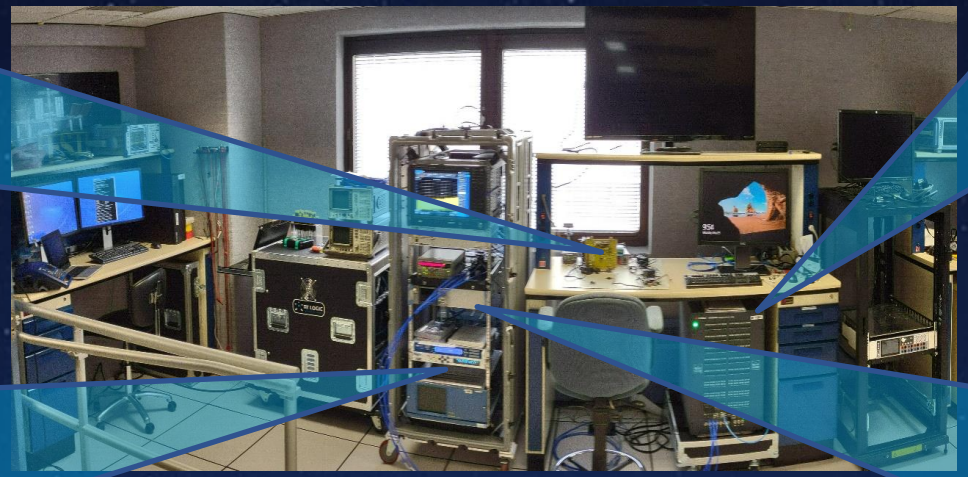
- NASA's projected communication architecture requires autonomy, flexibility, resiliency, and interoperability.
- Cognitive radio / networking technology can address many of challenges of a complex, dynamic environment.
- Interaction between physical layer and networking layer is key, driving need for high-fidelity emulation testbeds for evaluation + development

TESTBED OVERVIEW

User Spacecraft Emulation

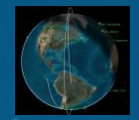
- Software Defined Radios hosts waveform for each service
- Automation software loads waveforms per event schedule
- Flight computer generates representative data for mission



Multi-channel RF Emulator

- Spacecraft orbital dynamics modeling, automatically calculated
- Channel impairments: AWGN, delay, Doppler, fading
- Interference Injection, weather impairments, link disruptions

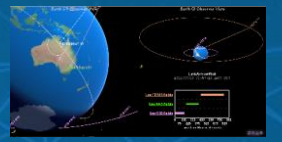
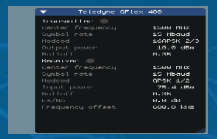



Service Provider Emulation

- Emulate Direct-to-Earth and Space Relay providers
- Provider-unique waveforms and modems
- Government and Commercial services

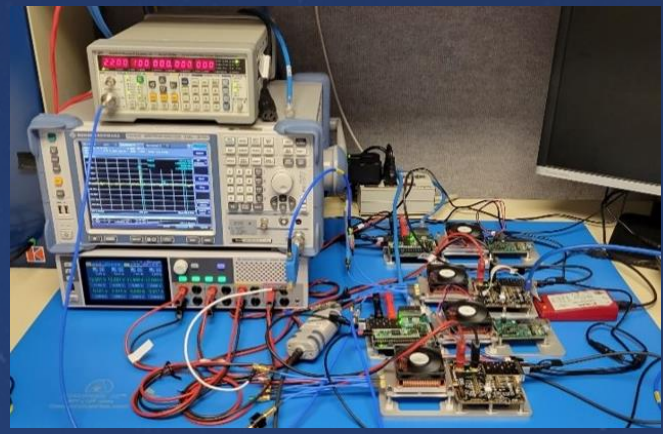
Testbed Controller

- Automates operations of Testbed
- Visualization of link status, scheduled events, data transfer performance
- System monitor / data logging

TESTBED OVERVIEW
USER SPACECRAFT EMULATION

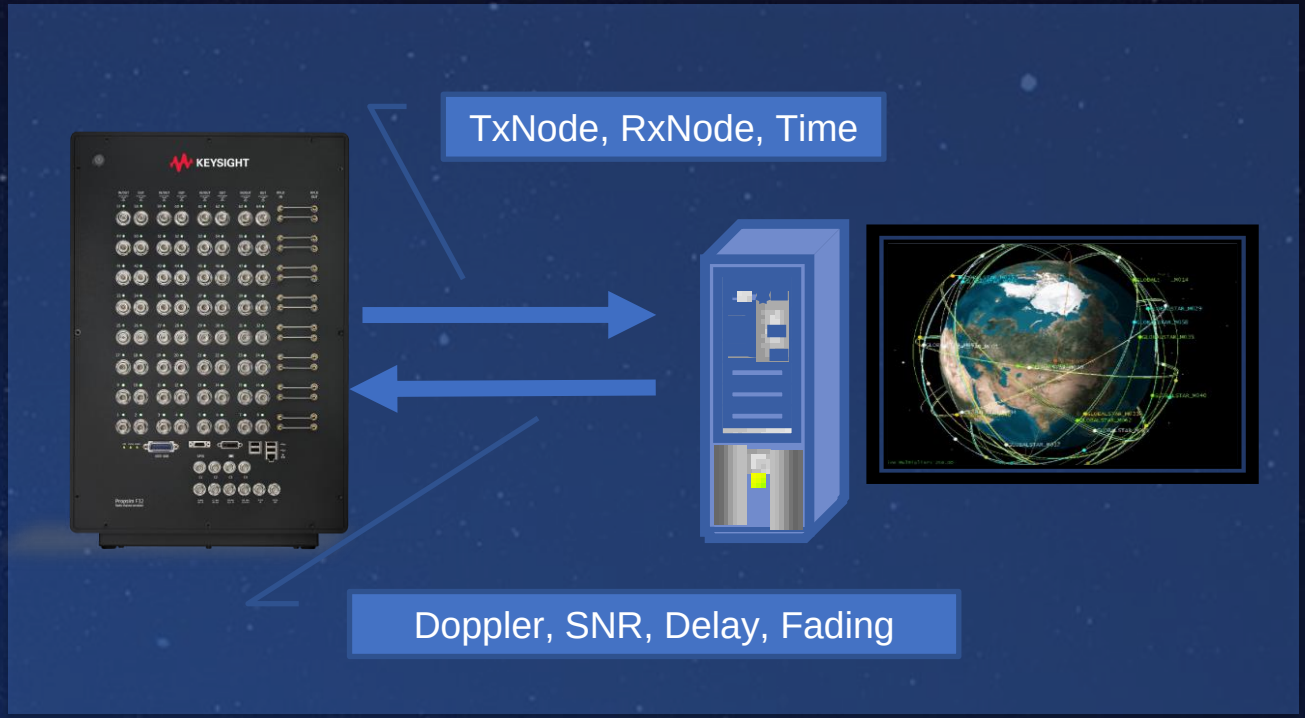
- Communication subsystem and flight computer emulated in testbed
- SDR is envisioned to be a wideband RF terminal, tunable over wide RF range, interoperability with Gov/Commercial frequency allocations.
  - CesiumAstro SDR engineering model represents this function with flight-like hardware
- Flight-heritage waveform applications from NASA's Software Catalog and commercial IP cores.
- Flight computer hosts
  - Data Generation
  - Storage Manager
  - DTN Networking Software
  - Service Request Automation



Waveform	Modulation	Max Rate	Function
Spread Spectrum	SS-BPSK	193 kbps	Gov. Space Relay
QPSK	QPSK	31 Mbps	DTE S-band
DVB-S2	PSK / APSK	31 Mbaud	Comm Space Relay
High-Rate BW Eff.	PSK / APSK	83 Mbaud	DTE Ka-band

TESTBED OVERVIEW
RF CHANNEL EMULATOR / ORBITAL DYNAMICS

- Autonomous communications systems can request service on-demand, RF channel emulator operation needs to be automated
- AGI's System Tool Kit (STK) provides API-driven interface for responding to channel conditions between nodes at given time
- Testbed Controller loads and triggers channel emulation per the event schedule between desired nodes.
- RF interference can be injected with external Vector Signal Generator, or as additional input to RF channel emulator with modeled channel conditions.



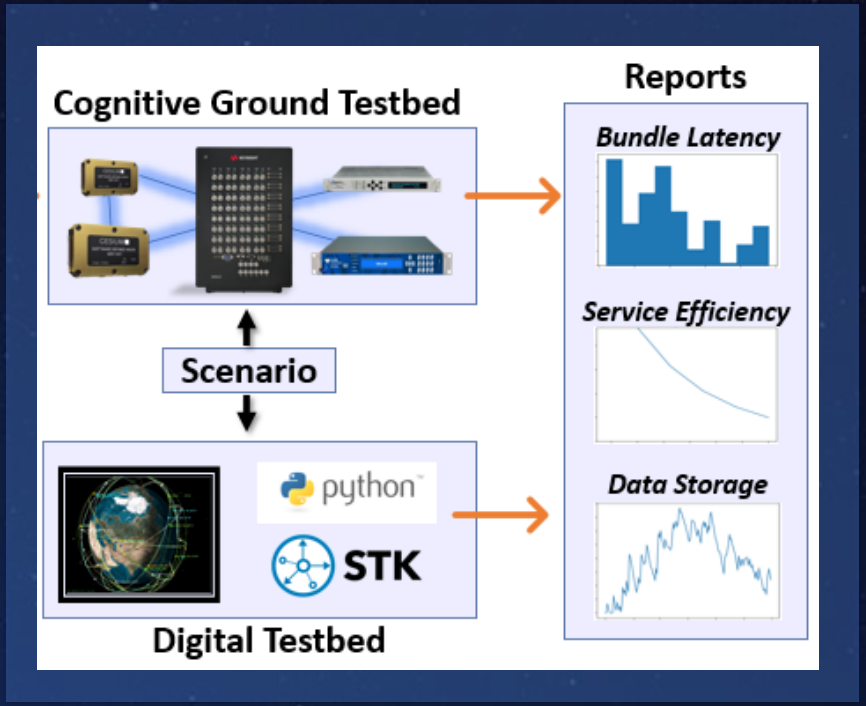
TESTBED OVERVIEW
SERVICE PROVIDER EMULATION

- Each provider's set of ground stations and/or relay satellites modeled, including location, and key attributes (EIRP, G/T)
- Commercial modems are either representative, or exact copy of the provider's service
- For scheduling, each provider Service availability modeled as a probability of acceptance

	Service Providers				
	Gov Relay	CSP Relay #1	CSP Relay #2	DTE #1	DTE #2
Provider Location	GEO (TDRSS)	GEO	MEO	Polar Network	Global Network
Frequency	S/Ka	Ka	Ka	S/Ka	S/X
Waveform	SNUG	DVB-S2*	DVB-S2**	CCSDS	CCSDS / DVB-S2
Emulation Modem	RT Logic TSIM	Qflex-400	Comtech CDM-760	Amergint / Zodiac	Kratos qRadio

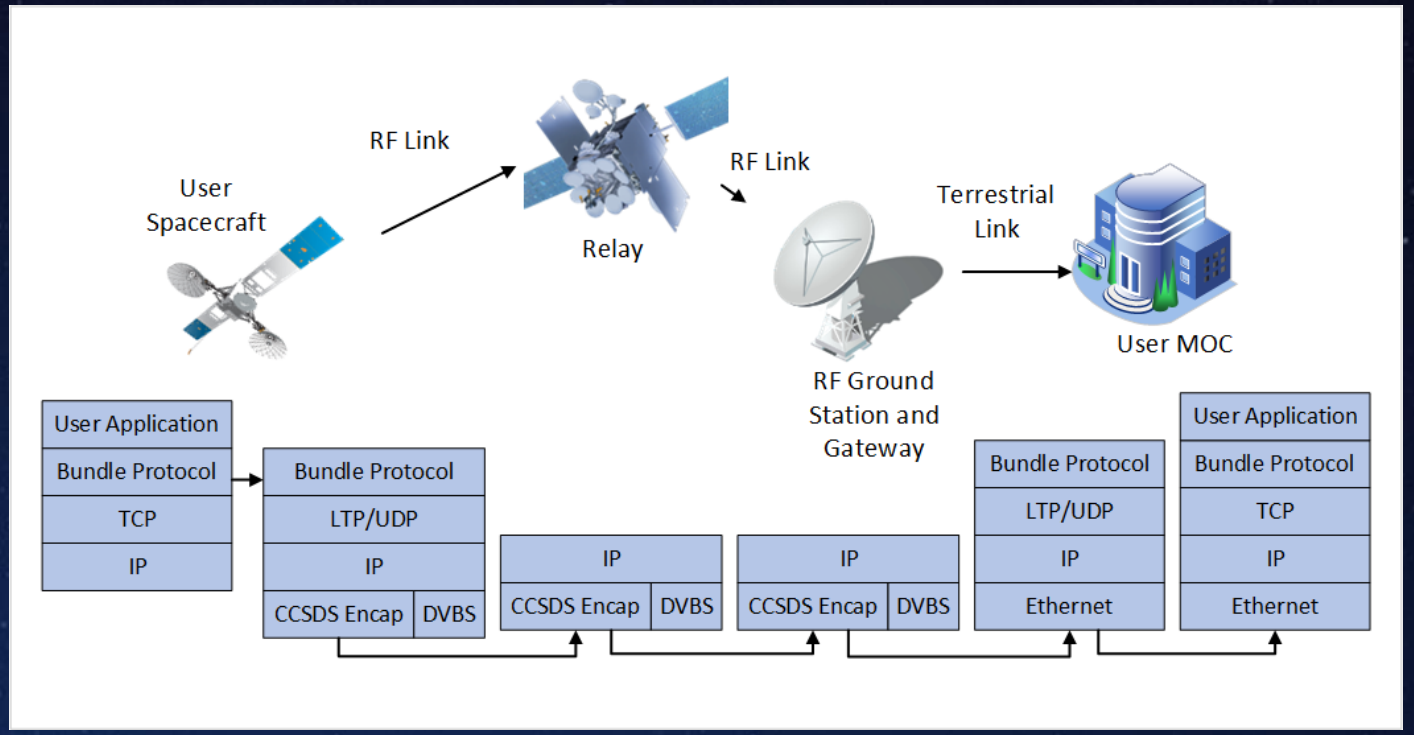
SCENARIO DEFINITION

- Scenario definitions are used to initialize testbed components and assist with version controlling test operations for reproducibility.
  - Defined as set of CSV-formatted files.
- System runs in real-time – using current TLE and current time
- Describes the spacecraft orbit, ground station location, RF performance (EIRP, G/T), and associated waveform
  - Enables addition / subtraction of service providers
- Also defines spacecraft data generation
  - Data-rate
  - Bursty, Continuous
  - Priority



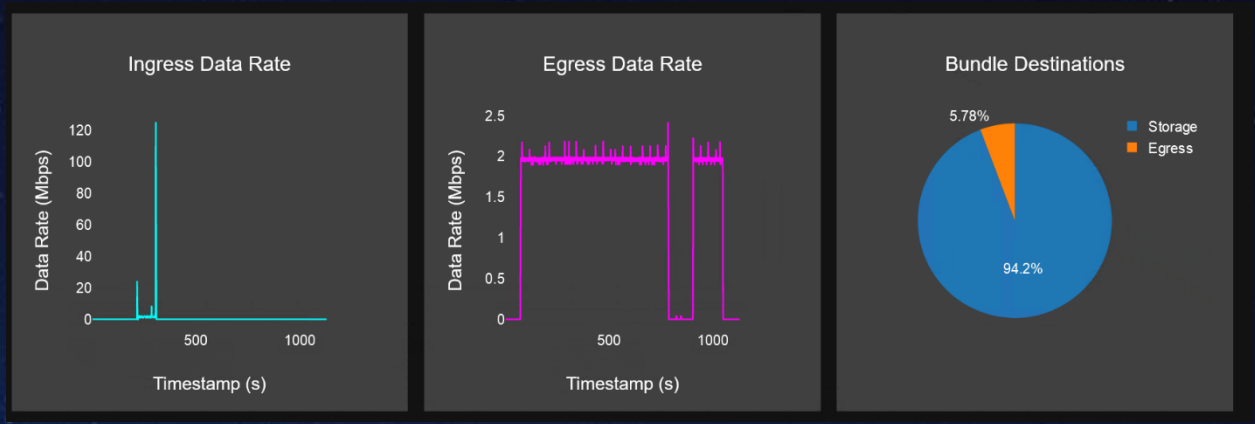
NETWORKING DATA FLOW

- The testbed uses the HDTN file transfer application to convert files to bundles
- The space to ground link uses LTP over UDP/IP that can be converted into either CCSDS or commercial protocols and waveforms
- The packets on the ground will reach a DTN gateway
- BP can run over terrestrial protocols from the gateway to the user MOC



System Metrics

- HDTN is used to collect and log system metrics at the spacecraft and MOC
- The HDTN web interface provides a graphical display

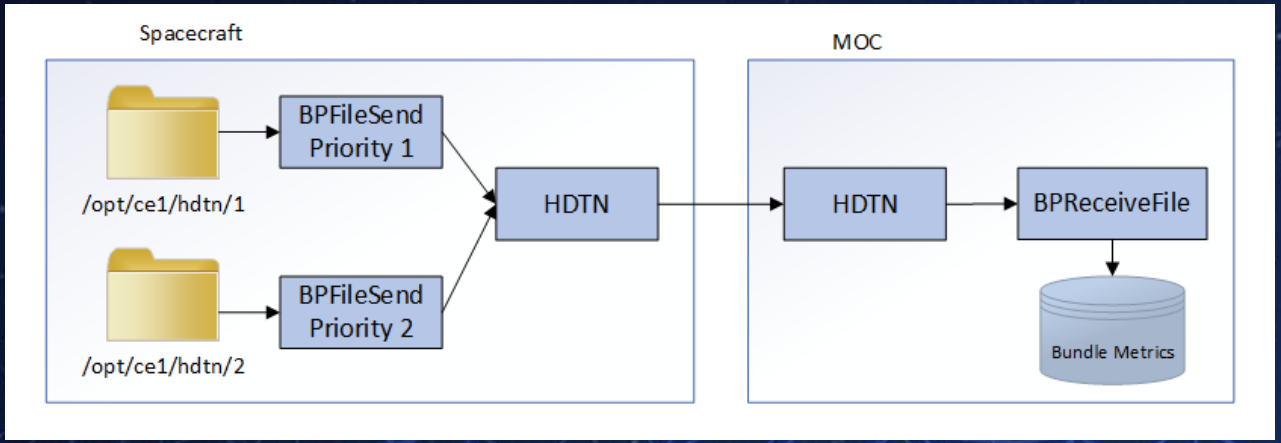


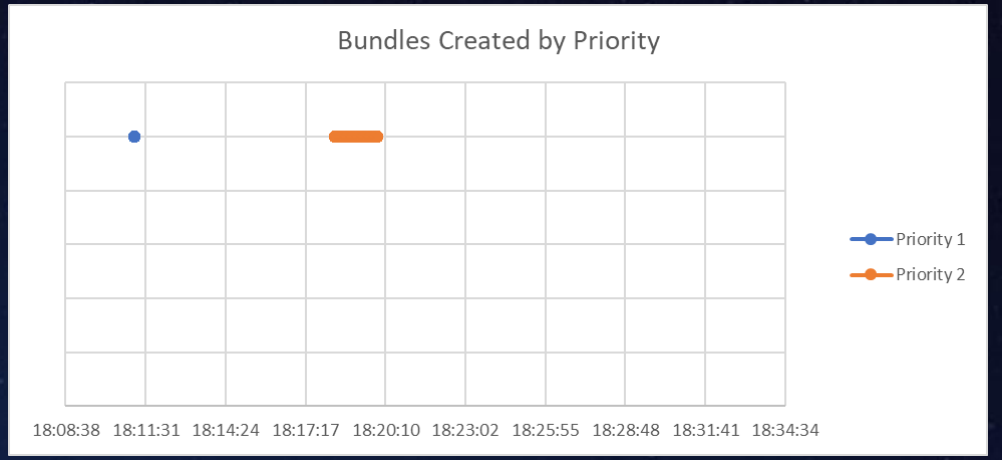
Sample Metrics File

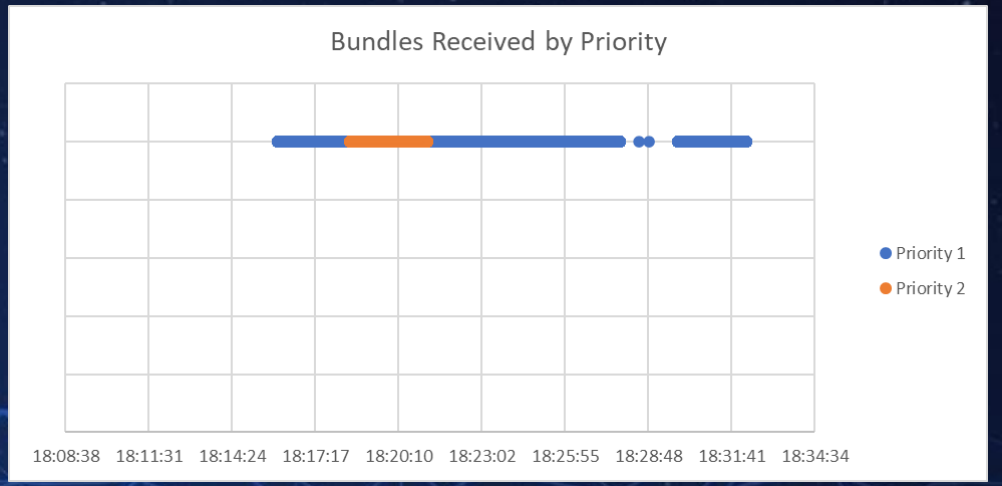
timestamp(ms)	bundle_source_to_sink_latency_s	priority	destination_node_id	destination_service_id	source_node_id	source_service_id	expiration_ms	lifetime_seconds	creation_seconds_since_2000
0	293	1	2	1	1	1	7.38E+11	30	737575866
12	293	1	2	1	1	1	7.38E+11	30	737575866
24	293	1	2	1	1	1	7.38E+11	30	737575866
38	293	1	2	1	1	1	7.38E+11	30	737575866
50	293	1	2	1	1	1	7.38E+11	30	737575866
63	293	1	2	1	1	1	7.38E+11	30	737575866
76	293	1	2	1	1	1	7.38E+11	30	737575866
89	293	1	2	1	1	1	7.38E+11	30	737575866

Data Generation and Priority

- Custom scripts generate both bursty and continuous data of different files sizes and priority
- HDTN's storage module ensures high priority (2) data is transmitted before low priority (1) data

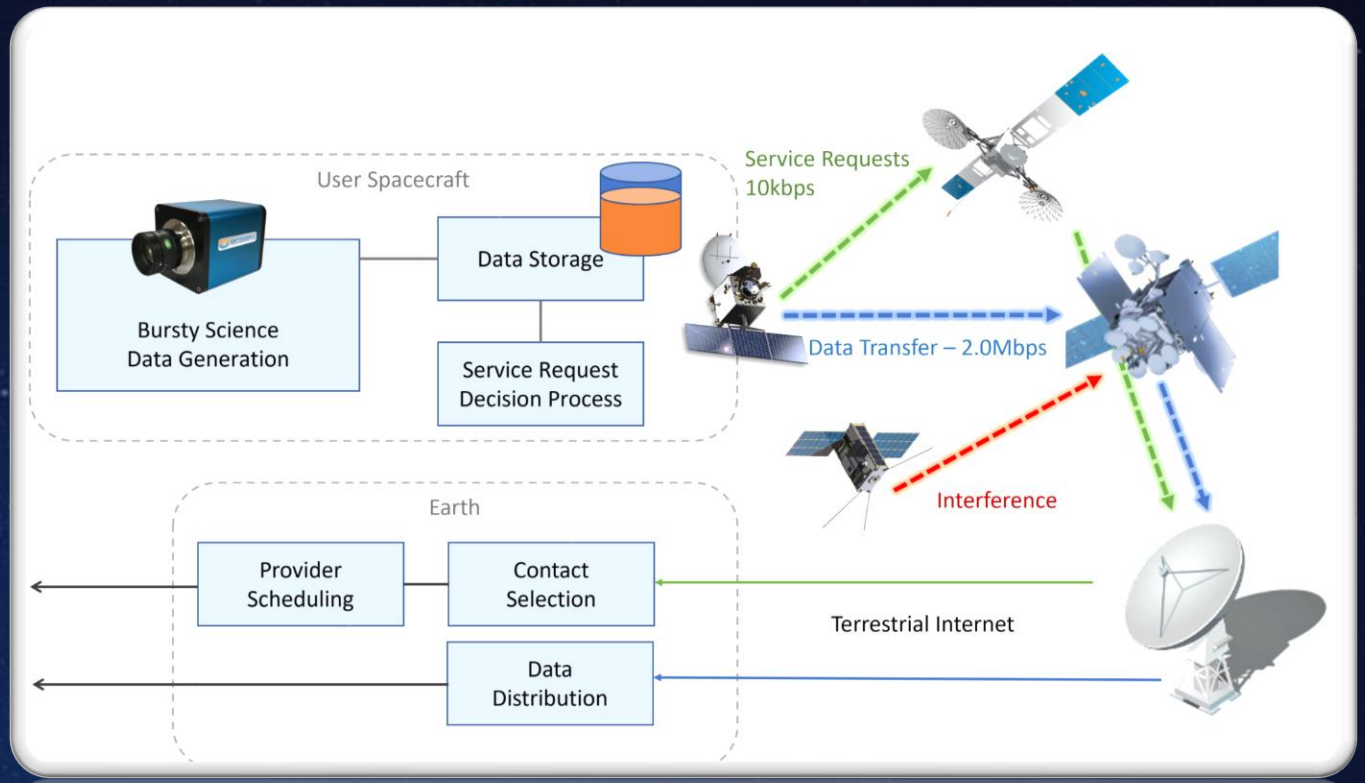






END-TO-END TESTING
DEMONSTRATION SCENARIO

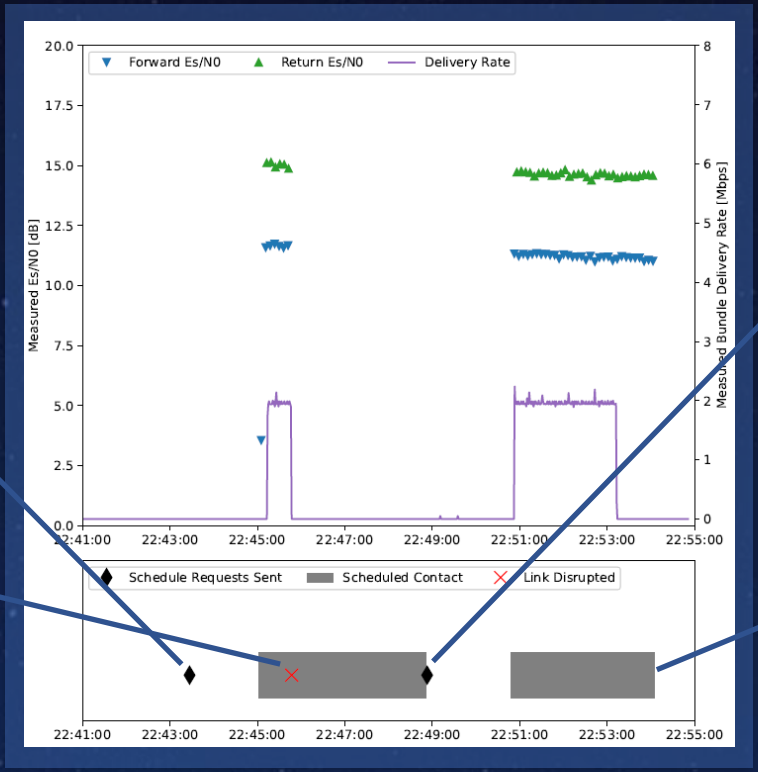
- As initial test, emulated LEO science mission modeled in medium inclined orbit (51 degree)
- Mission serviced by Gov./Comm. space relays
- Spacecraft generates high-priority science (weather, transient astronomical phenomena, etc)
- Intermittent disruption due to equipment misconfiguration or interference



END-TO-END TESTING
DEMONSTRATION RESULTS

Automatic Request for Service for High-Priority Science

RF Interference Disrupts Link



Automatic Request for New Service after failed pass

Successful data transfer

Initial demonstration demonstrates core functionality of the testbed, including end-to-end DTN data flow, automated operations of the testbed, and supporting testing of autonomous/cognitive communications systems, without human interaction.

CONCLUSION

- High-fidelity, emulation environment critical for developing cognitive radio/networking application in realistic environment
- Testbed has been developed, supporting automated operations, and initial demonstrations completed.
- Follow-up work includes additional space-craft nodes to support additional use cases.