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Space-Ground Communications Testbed

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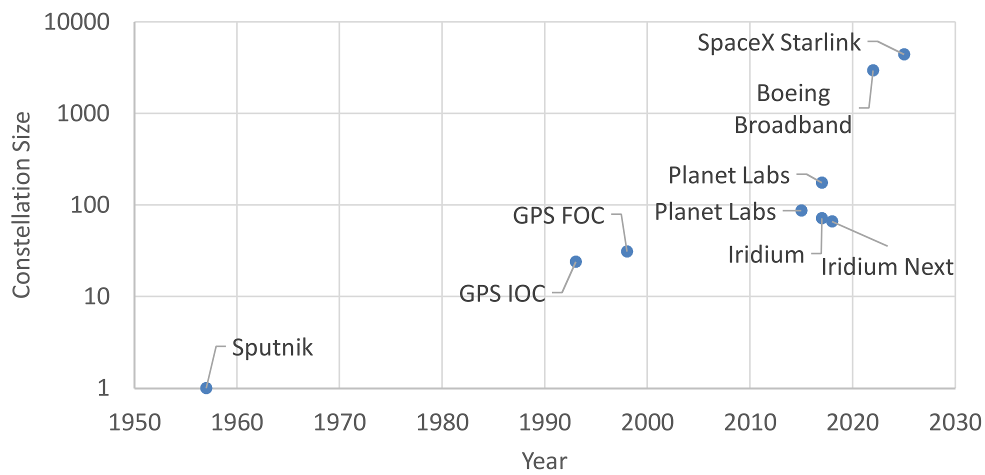
Evolving Space RF Complexity

- Traditional constellation sizes in the tens of satellites
- Modern constellation sizes proposed in the **hundreds** to **thousands** of satellites
- Planet Labs: 175 in 2017
- SpaceX Starlink: 4425 in 2025
- Presents new radio frequency (RF) spectrum management challenges
  - Many of these new satellites are in adjacent frequencies bands
  - Inadvertent communication issues will be difficult to predict or detect



Next-gen Space Situational Awareness (SSA) must address an increasingly complex space RF environment

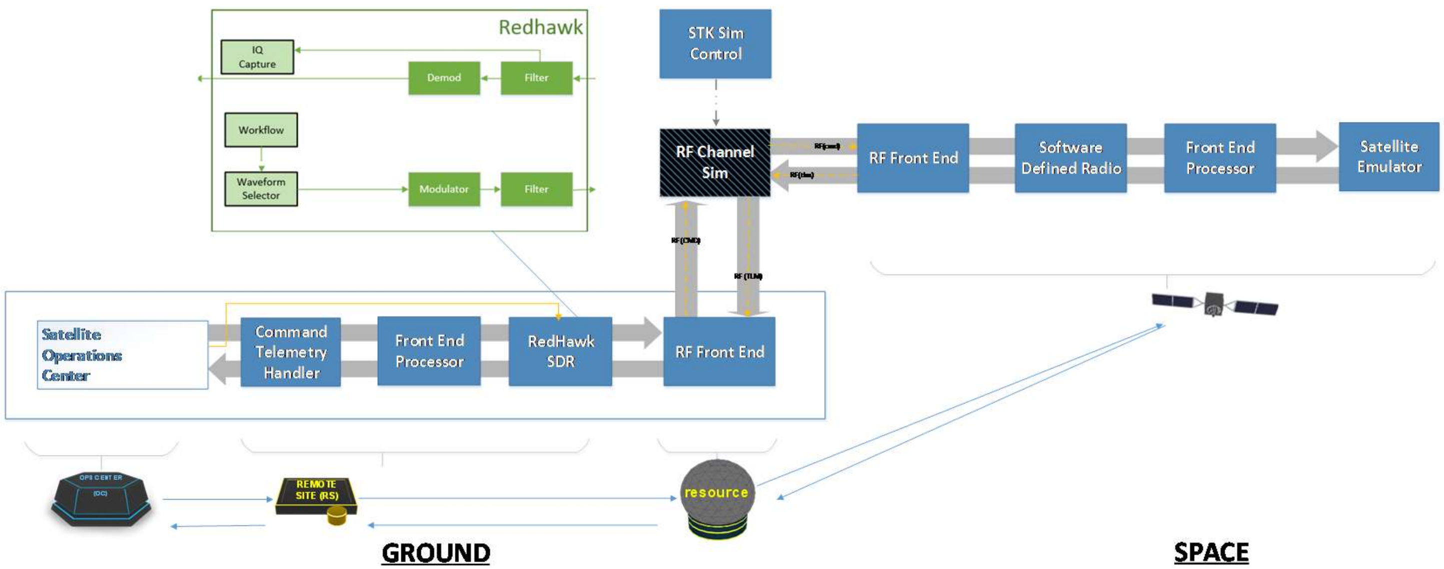
A Space Comms Troubleshooting Need

- Today's satellite operators are primarily focused on satellite or constellation performance parameters that specifically impact their mission
  - Most communication anomalies are attributed to problems within the specific hardware or software for the system
  - For the most part operators will not start to investigate external sources of interference until internal checks have been completely exhausted
- Even when external interference is suspected, there are very few tools at the operator's disposal to quickly determine the cause of interference:
  - Reference Joint Space Operations Center (JSpOC) warnings to infer which satellites might be causing interference. However, these would likely be **lacking detail related to how RF signals are actually being impacted.**
  - Some commercially available tools that would allow operators to assess RF performance and possible sources of interference, but many of these tools are **limited to simulation in software**.

Enable satellite operators to run high-fidelity **RF hardware-in-the-loop** simulations based on real world RF behavior to both identify and predict sources of current and future interference.

The Space Protection RF Testbed

- Developed for hardware-in-the-loop (HIL) simulation of various space communication scenarios
- Includes
  - Reconfigurable software-defined radios
  - Ground station emulators
  - High-fidelity satellite emulators
- Systems-toolkit (STK) driven channel simulator
- Transmit/receive actual satellite commands and telemetry over a real-time simulated RF space link
  - Doppler, path-loss, time delay, etc.
  - Signal up/down conversion



Ground Station Resources

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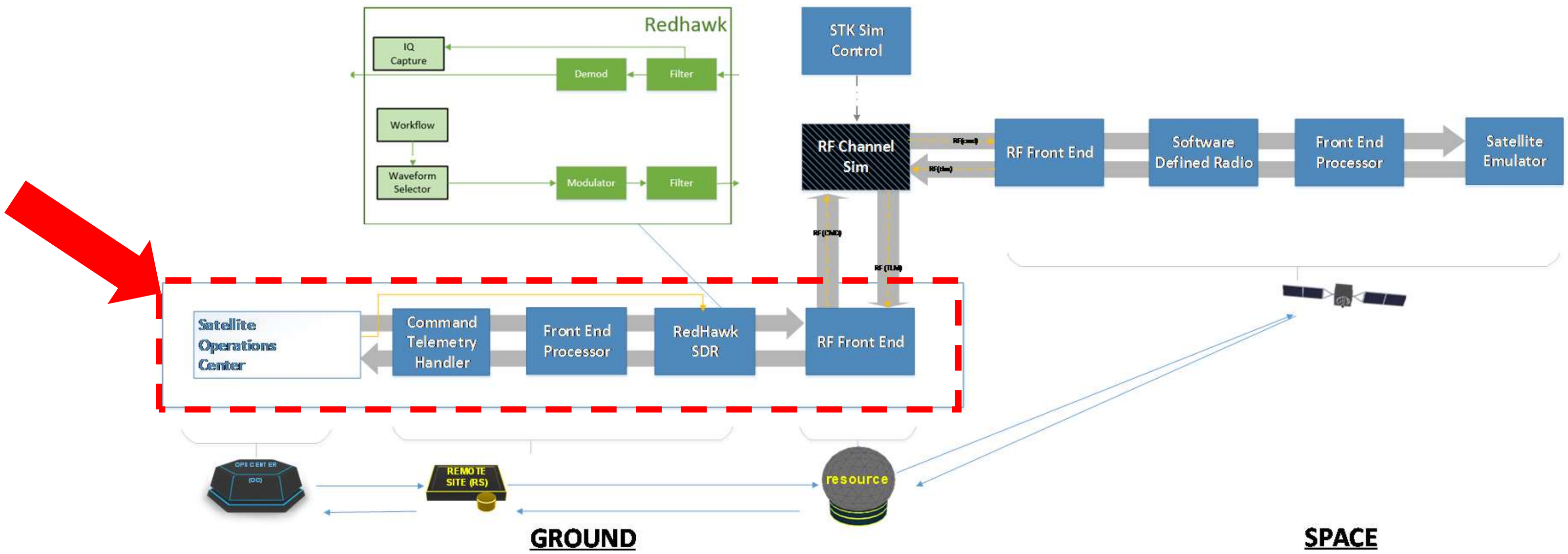
- Ground station assets are designed into an STK scenario which simulates each ground station's physics including:
  - Asset's location in real-time
  - Antenna system and properties
  - Communication link availability
- Each ground asset is then assigned additional hardware and software components within the testbed:
  - A command and telemetry handling component is deployed and connected to Satellite Operations Center (SOC) software and a generic front end processor.
  - The command and telemetry handler and front end processor:
    - Formats commands before modulation and transmission
    - Extracts telemetry from a demodulated bit stream for SOC use
  - Formatted telemetry and command packets are passed on a configurable software defined radio (SDR) component that performs digital signals processing (DSP) to:
    - Create a stream of in-phase/quadrature (IQ) data for transmission
    - Demodulate to a bit stream of received data for the FEP
  - IQ data is passed to and from a hardware transceiver device that creates the ground station's transmitted RF signal as well as receives any RF signals from the channel simulator



Space Asset Resources

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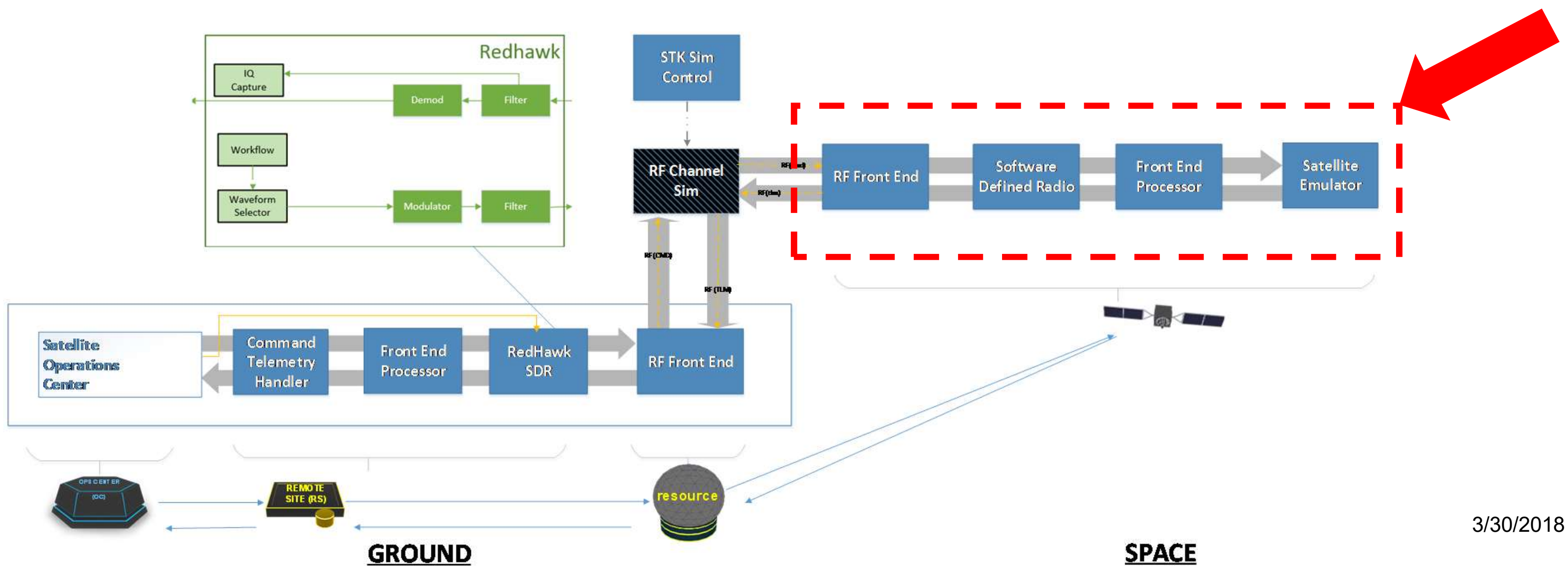
- Space assets are designed into an STK scenario which simulates each satellite's physics including:
  - Orbit parameters and propagation in real-time
  - Antenna system characteristics
  - Communication link availability.
- Transceiver hardware and SDRs are then allocated to desired satellite assets to generate and receive actual RF signals.
- A generic satellite emulator is deployed to generate and provide realistic simulated spacecraft telemetry.
- Telemetry is packetized and formatted in a front-end processor component, modulated into an IQ stream in the satellite's SDR, and finally converted to an analog signal
- Received commands are demodulated and framed before being passed onto the satellite emulator for processing



RF Environment Simulator

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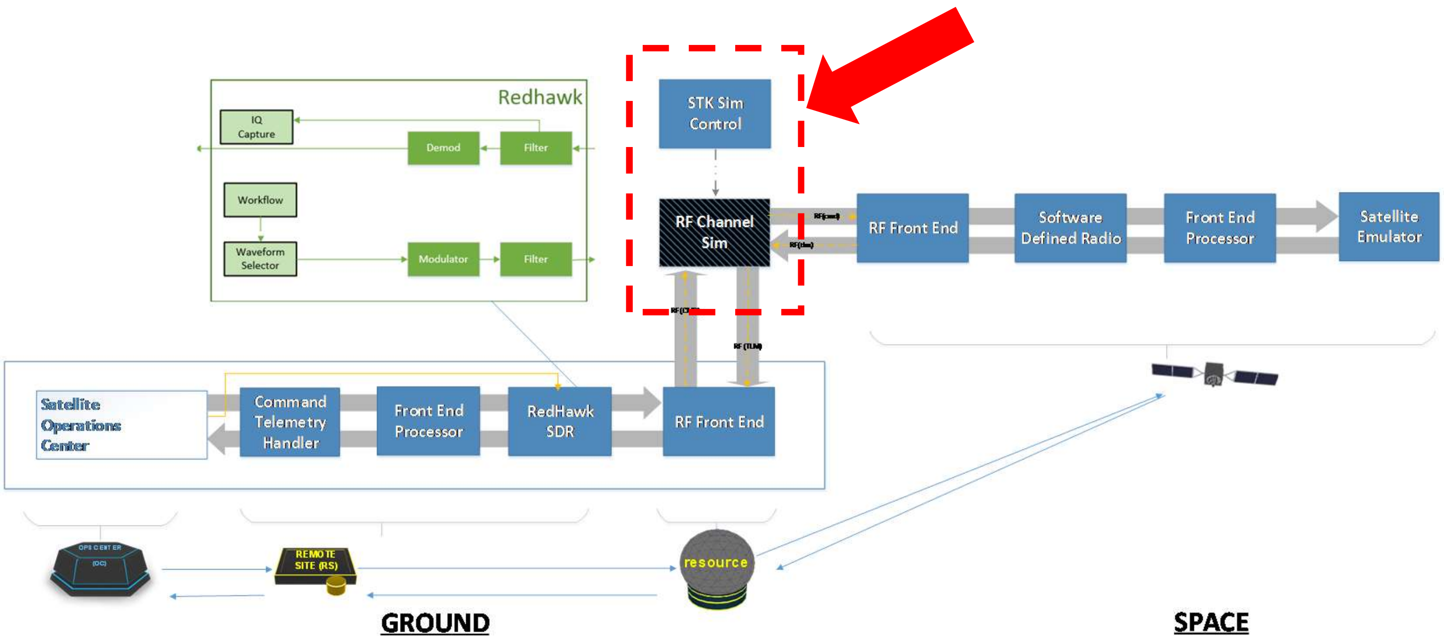
- Managed in STK, satellites and ground stations are defined in a scenario to obtain the desired simulation conditions
- A high fidelity channel simulator controls RF conditions in real-time based on asset positions, velocity, antenna designs, antenna orientations, and RF environmental models within STK. Satellite orbits are propagated in real-time and actual communication windows are adhered to according to ground station locations.
- As many links can be simulated as there are channels available on the channel simulator.
- Real-time control and synchronization of the testbed RF hardware is maintained by a dedicated high-accuracy GPS frequency reference with multiple 10 MHz and pulse-per-second outputs



Use Cases

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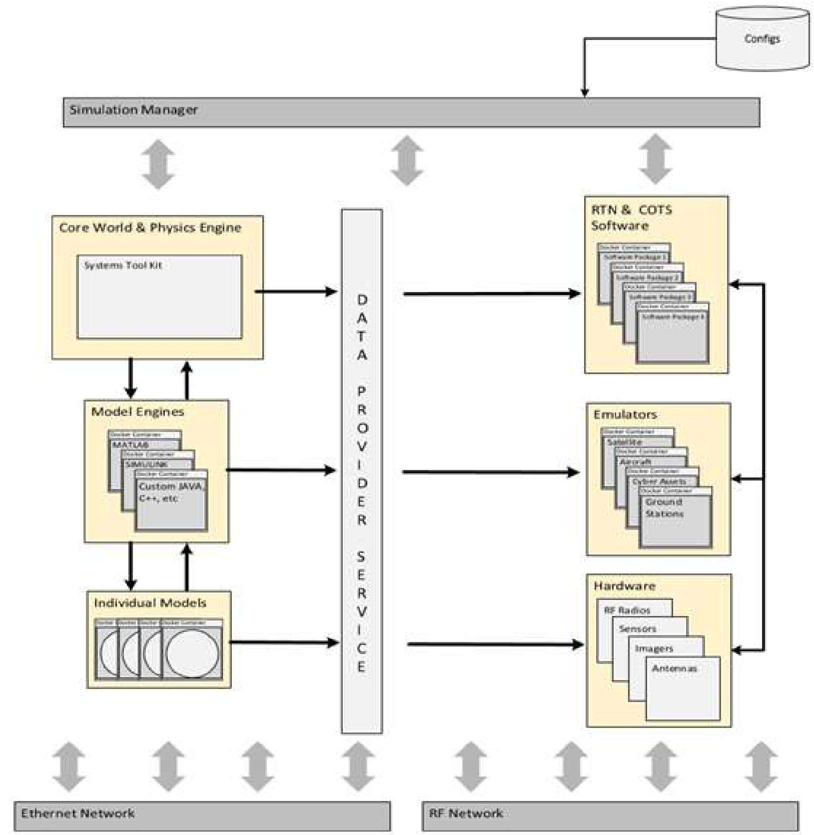
- The testbed was designed to be highly configurable and scalable to support a broad number of use cases:
  - Simulation only configuration for rapid mission analysis to support broad trades
  - Hardware-in-the-loop configuration for extremely high fidelity analyses
  - Various degrees in-between simulation-only and extensive hardware-in-the-loop

- The Space Protection RF Testbed provides a unique capability to:
  - Characterize and simulate phenomena as it occurs real-time
  - Troubleshoot anomalies of interference or other loss of communications
  - Recreate live space-to-ground RF conditions
  - Simulate, detect, and correct unintended interferences from a new launch (e.g. the insertion of a hundred or more new objects into orbit)

Troubleshooting commands, expensive satellite maneuvers, and what-if scenarios can be simulated cheaply and quickly, providing invaluable and timely analysis of critical mission issues to determine root cause before operational decisions are made.

Configurability and Scalability

- Two of the key characteristics of the RF testbed are the considerations given to configurability and scalability to create a dynamic, composable RF analysis capability. In our test case,
  - STK is used as the core physics based model engine to generate the physical data between objects as well as to drive the RF channel simulator.
  - Using a configuration file based approach, the number and types of assets and their corresponding properties can be programmatically added to an STK scenario at any scale required, with the number of simulated RF links limited only by the number of available channels on the channel simulator.
- Future work aims to have all components attached to a given asset assigned and deployed using containerization technology. This allows:
  - Scalability
  - Repeatability
  - Maintainability
- In an example test case, COSMOS could be used to represent both a satellite and a ground station asset, generate realistic commands, telemetry, etc.
- In future iterations, a hardware RF front end device connected through the RF channel simulator could be automatically assigned along with an emulator to the STK object, thus forming a rapidly configurable space RF hardware in the loop testing capability.
- Additional hardware, such as flight computers and sensors, could also be added in this manner.



Proposed improvements to the Space Protection RF Testbed aim to increase configurability and scalability

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Questions?

The Space RF Testbed Team

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