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Space-Ground Communications Testbed

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ABSTRACT

Traditional satellite operations focus on ensuring specific individual satellite constellations are optimally performing their missions. The satellite controllers are generally a mix of ground, vehicle, and payload specialists. These types of operators treat constellation issues as system anomalies and are trained to troubleshoot specific issues. The traditional skillset for basic satellite command control may not be sufficient when trying to protect our space assets. The broad tenets implied by “Space Protection” will require operators to be knowledgeable of numerous sources of interference, multi-constellation situational awareness, and real world intelligence to develop appropriate courses of action. This broad approach to space mission operations implies a paradigm shift to technologies and tactics that focus on assuring that all space assets can be accessed at all times regardless of mission orbit or configuration.

To meet this need, Raytheon has built a space-ground communications testbed which provides a high fidelity operationally relevant environment for Mission Management, Command and Control testing, bidirectional space to ground communications, anomaly resolution, and anomaly scenario development. This system can emulate/simulate a diverse number of satellites and ground system characteristics in order to evaluate approaches to maintain communications through degraded environmental conditions and radio frequency interference. In addition, the system can also evaluate the network bandwidth required between local and remote system services to determine the appropriate level needed to maintain command authority over spacecraft and/or ground systems. Using this testbed, decision makers are able to execute multiple scenarios using varying satellite and ground characteristics with confidence that their findings are applicable in real world operations.

INTRODUCTION

In the years following the introduction of the Space Age the celestial landscape has become increasingly crowded, diverse, and contested. This growth in the number of objects on orbit has been paralleled by a growth in the world’s dependency on space to provide immeasurable benefits including precise navigation and timing, rapid worldwide communications, and better forecasting. These capabilities are essential to our day-to-day lives and must be maintained. However, as more and more objects are put into space, it can be difficult to understand all of their interactions including RF transmissions and maneuvers. This limited awareness leads to the potential for a loss of capabilities. To insure capability availability amidst this astronomic growth in volume and dependency, we must have robust Space Situational Awareness (SSA). At a minimum, SSA includes understanding what objects are in space, what objects are on the ground, what RF emissions are occurring between objects, what maneuvers are possible, and what the objects are trying to do. SSA capabilities are limited by physics and geometry and, depending on the orbital regimes, very limited observations may be available. Thus, simulation can be an important tool for gaining understanding and insight into what is occurring in space.

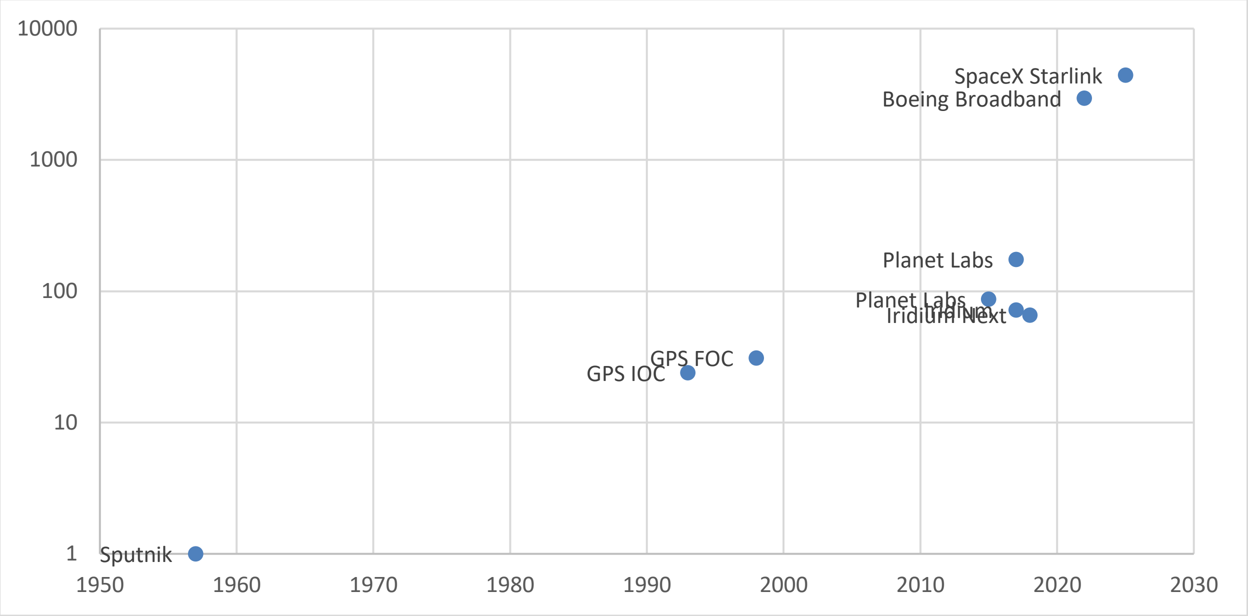

Figure 1. Examples of growing constellation sizes

Figure 1 shows a few examples of constellation sizes and how they have grown over the years. Traditional constellations have been smaller with focused missions. For example the GPS constellation typically sits at around 32 active satellites with a handful of satellites in orbit as backups. At its inception, the GPS constellation would have been considered to be fairly large. However, when compared to Iridium, Planet Labs, and the projected multi-thousand satellite SpaceX Starlink constellation we see that the definition of “large constellations” has changed. If this trend continues, the burden of improved SSA becomes even more daunting.

We must be able to quickly predict and assess impacts or conjunctions between objects. Knowledge of satellites’ positions, though important, is only half of the equation. Complicating matters even further is that the majority of these objects rely on communication with ground systems to receive and transmit critical commands and telemetry. This communication amongst many thousands of objects creates very complicated RF spectrum management issues. Many satellites are operating in the same or adjacent frequency bands which can lead to inadvertent communications issues that could be tough to predict or detect.

BACKGROUND

Current satellite operations may not have all of the capabilities needed to manage these complex multi-source RF issues. Today's satellite operators are primarily focused on satellite or constellation performance parameters that specifically impact their mission. To that end, 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 the interference. One of the common methods in use today would be to reference the conjunction reports issued by the Joint Space Operations Center (JSpOC). JSpOC issues conjunction reports whenever a satellite may be coming within a specific distance of another satellite. JSpOC warnings are based on collections from the Space Surveillance Network (SSN), a system of sensors tasked with tracking the locations of objects in orbit. Operators could use these conjunction reports to infer which satellites might be causing interference but the assumptions would likely be lacking in detail related to how RF signals are actually being impacted. There are 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. Enabling operators and decision makers to access a suite of tools that incorporate hardware and software combined with actual RF components will mean that operators can run high fidelity simulations based on real world RF behavior to both identify and predict many sources of current and future interference. The following paragraphs give a concise overview of the Space Protection RF Testbed prototype currently being developed by Raytheon to help address these needs.

SPACE PROTECTION RF TESTBED

Of the many facets that go into Space Protection, characterization and control of the radio frequency (RF) spectrum is of significant interest and value. As stated earlier, as the number of space objects, both operational and non-operational, increases so too does the complexity and density of the RF spectrum. Such density can lead to malicious and benign actions that can reduce or eliminate operational space asset capabilities. As part of the overall Space Protection effort, an RF simulation testbed was conceived to model, simulate, and reproduce realistic RF signals from the space environment in order to characterize and utilize them in command and control simulations.

A shown in Figure 2, several major components together makeup the RF testbed: Satellite Operations Centers software, ground station resources, an RF environment simulator, and space asset resources. Each resource has associated hardware and software that together emulate the asset's RF capability.

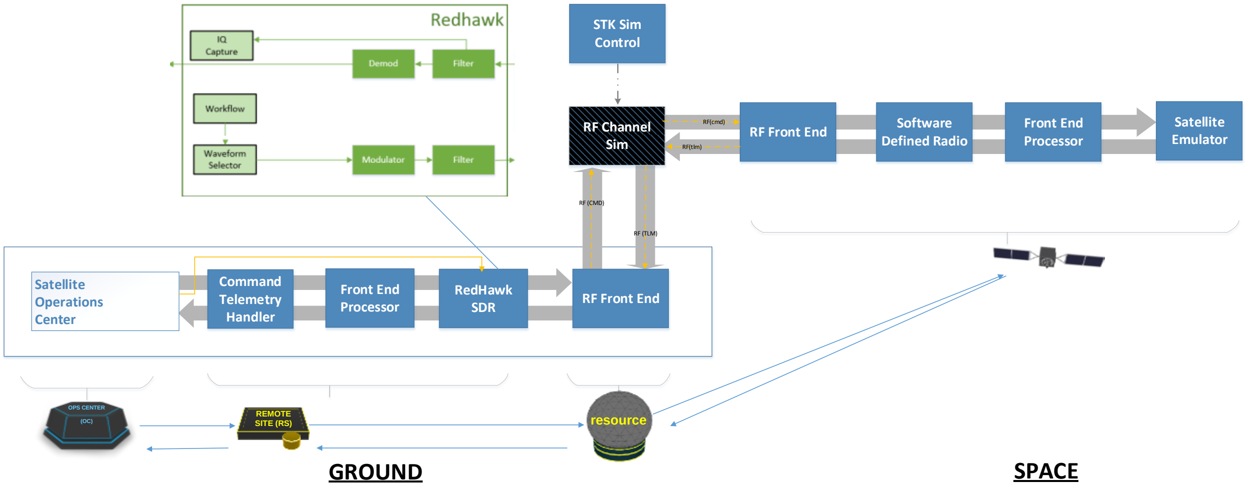

Figure 2. Illustration of major testbed components and their collective simulation scenario representations

Ground Station Resources

The RF testbed creates one or more ground station assets to emulate the ground segment in a given scenario. Each ground station is first deployed into a physics-based model engine, in this case designed into a Systems Toolkit (STK) scenario, which simulates each asset's location, antenna system and properties, and communication link availability and characteristics in real-time as the scenario progresses. Each ground asset is then assigned additional hardware and software components within the testbed in order to create an actual RF signal in the lab environment. A command and telemetry handling component is deployed and connected to both the Satellite Operations Center and a generic front end processor. The formatted telemetry and command packets are then passed on to (or received by) the software defined radio (SDR) component that performs digital signals processing (DSP) to create a stream of in-phase/quadrature (IQ) data for transmission or a demodulated bit stream of received data. IQ data is passed on to a hardware transceiver device that creates the ground station's transmitted RF signal. This RF signal is then routed to an STK-controlled channel simulator where upconversion is performed before simulating propagation of the RF signal within the STK environment. Likewise, the ground station's received RF signals originate from the channel simulator (already downconverted) and are sent to the ground station's hardware transceiver where a received IQ stream is generated. The received IQ stream is then sent from the transceiver to the ground station's SDR and FEP for demodulation and framing into actual telemetry data that can be used by the Satellite Operations Center.

Space Asset Resources

Space assets for a given scenario are designed into an STK scenario which simulates each satellite's physics including orbit parameters, antenna system characteristics, and communication link availability in real-time as the scenario progresses. 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 intermediate frequency (IF) signal by hardware transceiver before being sent to the STK-controlled channel simulator. These IF signals are passed back and forth to the channel simulator where they can be upconverted and downconverted to and from actual satellite frequencies as necessary before being propagated through the simulated space environment by the channel simulator.

RF Environment Simulator

The RF environment between space and ground assets is simulated with a high-fidelity real-time channel simulator with a series of available RF channels. The channel simulator is controlled by STK, wherein individual RF links between assets are assigned and the appropriate RF signal effects are commanded to the channel simulator and conditioned appropriately to the signal including path losses, Doppler shift, and time delays. Channel conditions are controlled 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

The testbed was designed to be highly configurable and scalable to support a broad number of use cases. It can be run in a rapid, simulation only configuration for quick mission analysis to support broad trades, in a hardware-in-the-loop (HWIL) emulation configuration for extremely high fidelity analysis, or in various steps in-between those two extremes.

In the rapidly evolving space environment, the Space Protection RF testbed provides a unique capability to characterize and simulate phenomena as it occurs real-time. Government and commercial satellite operators for example could use the RF testbed to troubleshoot anomalies of interference or other loss of communications between their space and ground assets by recreating the live RF conditions in the lab on the RF testbed. Other example use cases could include detection and correction of unintended interference from a new launch, which may insert up to a hundred or more new objects into orbit. Having the hardware in the loop capability means test 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 RF links simulated limited only by the number of available channels on the RF channel simulator. The ultimate objective of future work is to have all components attached to a given asset assigned and deployed using containerization technology. This allows not only for scalability, but for easy repeatability and maintainability as well. In an example test case, the open-source satellite and ground station emulator COSMOS could be used to represent both a satellite and a ground station asset. In future iterations, a hardware RF front end device connected through the RF channel simulator could be assigned along with an emulator to the STK object, thus forming a realistic RF hardware in the loop testing capability. Additional hardware, such as flight computers and sensors, could also be added in this manner.

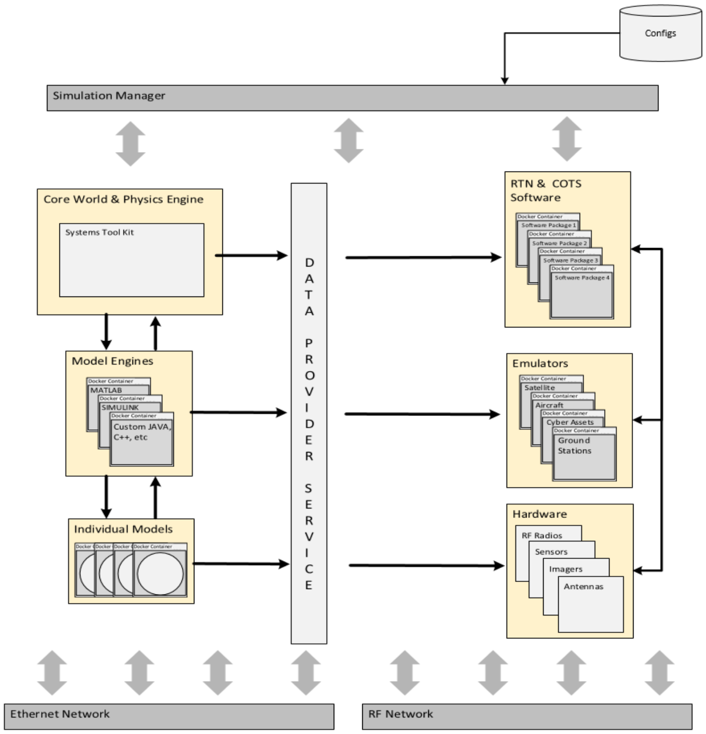

Figure 3. Possible future architecture of the RF testbed aimed at providing highly scalable RF analysis scenarios

SUMMARY

Given the changing space environment and our heavy reliance on space, protecting our space assets is essential. An important component of space protection is SSA, so that we can understand what is happening in space and, in the case of an anomaly, form an appropriate course of action to resolve it. The RF Testbed helps give us insight into what types of RFI could be occurring and a mechanism for determining the best courses of action to address RFI. Space protection is a broad mission area which will likely employ multiple different capabilities to meet mission needs. The Space Protection RF Testbed is a very important piece in the overall puzzle to meet the needs for future Space Protection capabilities