SSC17-P2-27

Emergent Trends for CubeSat Ground Systems - A University View

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ABSTRACT

For the past decade, academia has depended on the amateur radio frequencies and the concept of “one ground station, one satellite” mode of operations. With the changes in the International Amateur Radio Union (IARU), this model is no longer acceptable. Satellites must share ground systems and radio frequencies. Government systems often were plagued by the same design paradigm. To address this, the federal government has focused on the multi-mission satellite operations center (MMSOC). With the affordable price point of small satellites, more and more of these spacecraft will be entering the operational space and will need to be able to communicate with the ground. With more satellites, there must be a way to download the data, simplify integration and turn data in to knowledge.

1.0 BACKGROUND

The background areas of focus in this paper are tied to related topics: communications, standards, and big data analytics. In the past, these topics have been held as independent and were often not addressed with the theme of solving both areas with single sets of conclusions and resulting implementations.

Increasingly constrained RF management means that the Federal Communications Commission (FCC) will not issue a license for the amateur frequency bands without IARU coordination. The license was often issued from the FCC at the last minute. The Air Force Research Laboratory had their SHARC mission stranded on the International Space Station, unable to be released for flight because of delays in frequency license processing. Small satellite developers were also often creating software to interface with their spacecraft through RF systems that are one of a kind. Past activities initiated to help to avoid this paradigm. One example was the Global Educational Network for Satellite Operations (GENSO). This joint activity between the European Space Agency (ESA) and the University of Vigo in Spain was an excellent capability that provided the ability for a worldwide series of ground stations to be able to support multiple missions with networked ground stations. Unfortunately, when ESA attempted to transition GENSO to the open source community, the legal hassles become insurmountable and the program died.

Although nanosatellites will probably never be able to perform some of the missions larger satellites can achieve (such as synthetic aperture radar), for many other missions, the smaller footprint of a nanosatellite is achieving a great deal of military utility. Also, the definition of a CubeSat is morphing. In the past, organizations looked to 1U to 3U form factors. Today, more mission planners are looking to 6U and 12U form factors for performing their missions. An 8”x8”x12” satellite (at around 12kg) begins to provide the robustness for real military utility.

1.1 Communications

The amateur frequency bands have been used almost exclusively with the academic space community for the past decade. The COSMIAC Center has flown spacecraft and supported other satellites in their amateur frequency bands. Although problematic for obtaining licensing, it has successfully served many university nanosatellite programs (see references). The amateur frequency bands in the ultra-high frequency

(UHF) and very-high frequency (VHF) ranges should never be used for CubeSat activities for government missions. In the past, this practice has existed and waivers were obtained to allow for exceptions to the existing rules. Those days have changed. Where it becomes difficult is in the obvious mergers of academic and government missions. If any government funding is involved (almost inevitable due to the fact that universities are fiscally strapped), then the mission should not be allowed access to the amateur frequencies (per FCC and IARU guidance).

Research is now focused on much higher frequencies. Even use of Unified S-Band (USB) communications is becoming problematic. The existence of available frequencies, available data rates and other issues are pushing all future missions to look at Ka-Band as a minimum.

The activities related to this paper began approximately 18 months ago at the COSMIAC Research Center at the University of New Mexico (UNM). For the past decade, COSMIAC has operated multiple ground stations (see figure 1). These stations have supported the UHF and super-high frequency (SHF) bands performing operations for multiple satellites on a 24 hour a day basis. The station on the left (of Figure 1) now operates at 900 MHz and below. The station on the right (in Figure 1) is the Mobile CubeSat Command and Control (MC3) ground station which (at COSMIAC) is operating at 900 MHz and below. MC3 is an asset for US government small satellites and is designed to operate at the Unified S-Band (USB) but this capability with the accompanying three meter dish has not yet been installed at COSMIAC.

Figure 1 COSMIAC Ground Stations

Current research between the Air Force Research Laboratory (AFRL), the National Aeronautics Space Administration (NASA) and the COSMIAC Research Center at UNM are in the areas of W and V-bands. The research is designed to characterize the effects of weather and other environmental elements on the 72 GHz and 84 GHz frequency bands. The W/V-band Terrestrial Link Experiment (WTLE) in Albuquerque, New Mexico is designed to conduct a measurement campaign at 72 and 84 GHz, among the first atmospheric propagation measurements at these frequencies (see Figure 2).

Figure 2 WTLE 72 GHz and 82 GHz Test Experiment on the COSMIAC Roof

Agencies such as NASA and AFRL are recognizing the need to begin operating at higher frequencies and are now running test operational campaigns to study atmospherics on these frequencies with plans for flight experiments in the next five year.

1.2 Big Data Analytics

Another major change is in the application of big data analytics to telemetry data. In the past decade, one nanosatellite that was locked into a 9,600 bit per second communications link could be satisfied by a single ground station (or several by using the amateur community) and all the information could be stored in a spreadsheet type program for analysis. Today's government spacecraft have thousands of sensors and the big problem is related to how to deal with massive amounts of data. There are multiple problems. The first is dealing with one spacecraft. One large satellite such as a Global Positioning System (GPS) or the AFRL ESPA Augmented Geostationary Laboratory Experiment (EAGLE) satellite will have a massive amount of data that has such volume that it will be impossible for a team of individuals to be able to monitor all of it on a daily basis and the best that can be hoped for would be monitoring of errors and anomalies. The tricky part is how to take this amalgamation of data and use it to predict future failures. Although the value of the data from a single satellite is important to the war fighter, more importantly is the creation of intelligence and operational information from the nation's spacecraft systems. In the past, satellite operators would focus their attention on finding what they were looking for within downloaded sensor data. The problem with this mentality is that what is often not identified is actionable intelligence in data that is embedded within the satellite data that is often overlooked by operators. More importantly to intelligence agencies in the field is the amalgamation of the data from multiple satellites with seemingly unrelated mission focuses where only through the use of advanced large data analytics could it be possible to find the "nuggets" of information across multiple platforms where value added is hidden in the weeds. We use the term operational analytics to describe the data analytics that uses operational data in making better operational decisions, identifying actionable intelligence and being proactive in identifying potential issues before they occur.

Big data studies are one of the fastest growing areas in the commercial sector. According to Forbes, some relevant facts for commercializing big data processing tools and capabilities are that, by 2020, at least a third of all data will pass through the cloud. Additionally, 73% of organizations have already invested or plan to invest in big data by 2017.

1.3 Enterprise Ground System (EGS)

EGS is an Air Force term for a standard ground system architecture that can be used on a variety of missions. According to the USAF Space and Missile Systems Center (SMC) EGS government/industry standards working group's operating plan, the overarching objective for EGS is to define and implement an enterprise ground capability which enables the war fighter to fight and win a war in space. To accomplish this objective, the ground capability across mission areas must: (1) meet evolving enterprise mission needs, (2) be resilient to changing threat environments, (3) be affordable through system adaptations, and (4) be sustainable and responsive over time. EGS is focused on meeting this overarching objective through specification and utilization of a modern service based architecture, open source or government owned components, and more flexible acquisition approaches. This architecture supports the evolution of ground station technology to support new data acquisition techniques to include new RF spectrums and increased bandwidth and improved data analysis techniques such as the big data analytics approach discussed below.

2.0 INTRODUCTION AND DESCRIPTION OF THE EFFORT

The efforts at COSMIAC and their partners began approximately 18 months ago with the initiation of the big data analytics study. At this time, students were brought online and were assigned multiple tasks that included system configuration and analytics software development. Initial efforts were to take the NASA ICESAT mission where extensive datasets were available for analysis and begin to apply the tools to see how the machine learning algorithms could be developed and deployed. More recently, students have focused on common services architecture development to support a specific CubeSat mission.

2.1 Server Configuration

The servers used for this activity were easily obtained in house or on the public cloud. Our team developed a working knowledge of the configurations required to support each facet of the project. The packages used for the big data effort are shown in Figure 3. The common services architecture effort is currently hosted on VMware servers running Apache Tomcat.

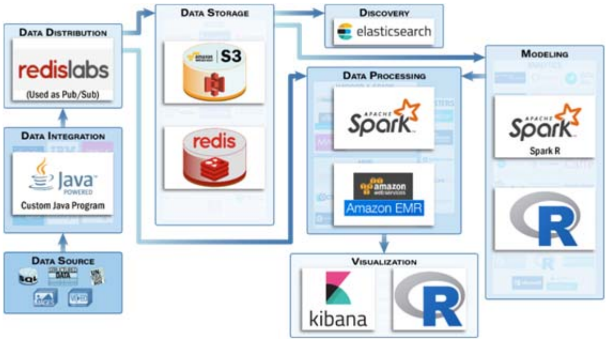

Figure 3. Functional architecture for an Operational Analytics implementation

2.2 Analytics Software Development

Various software packages are used for the big data analytics project. In this arena, the team has focused on packages that are normally utilized with Amazon Web Services (AWS) and NVIDIA platforms.

Our study adopted a three-step methodology to implementing operational analytics – Discovery, Modeling and Operations as shown in **Error! Reference source not found.** 4. This figure shows the three steps to implement operational analytics and the continuous feedback between learning and operational deployment.

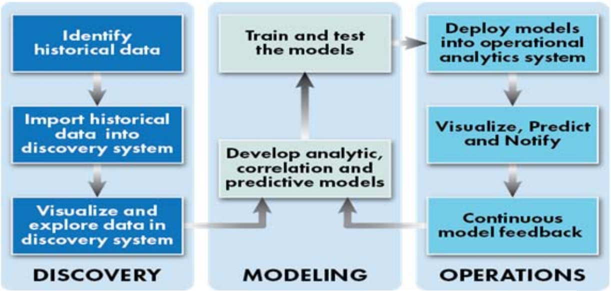

Figure 4. Operational Analytics Approach

The discovery phase uses data exploration and visualization to understand historical behavior of the target datasets. This phase attempts to understand the impacts of one dataset on another so that relationships can be determined and an analysis approach can be implemented.

The modeling phase extracted and expanded upon key insights observed in the discovery phase. Modeling for operational analytics is not a simulation seeking to recreate an external process, but rather a formalized set of insights gleaned from existing data and used to make accurate predictions about future data. These insights were used to automate and formalize the laborious process of data analytics. The culmination of this phase is the development of a model that can be used by operations to perform root cause analyses and perform predictive analytics.

The final phase is deploying the operational analytics system. A key element of building an operational system is to determine what data should be calculated and presented to the operators/analysts for evaluation. Figure 4 shows the functional architecture of our implementation.

2.3 Common Services Architecture

This effort was inspired by the Air Force initiative to develop such an architecture. The production architecture has major cyber security requirements that are implemented using commercial products. Our effort is focused on creating a similar capability using open source components that are not as resilient in the face of cyber-attack, but are available at a fraction of the cost. This enables a low cost integration environment to facilitate development, test, and integration of the mission related components of a ground system. Figure 5 shows a simplified view of the service oriented architecture.

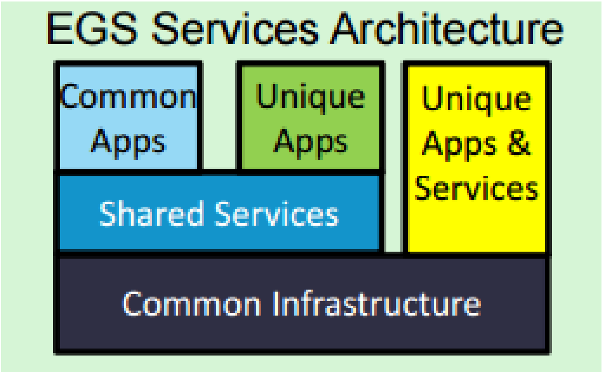

Figure 3. Common Services Architecture

SMC is currently using the publically available NASA GMSEC as its Enterprise Service Bus. The GMSEC architecture provides a scalable, extensible ground and flight system for future missions and enables the addition, deletion, and exchange of components to meet requirements of missions as they progress through their lifecycles. Other components are specified by SMC standards that are being developed the using an open participation model. Instantiating this architecture using open source components facilitates university participation in the creation of reusable ground services architecture components. The components currently being integrated are:

- NASA GMSEC
- Apache Tomcat
- Apache Active MQ
- NRL NEPTUNE

Other components will be integrated or developed as they become available.

3.0 TECHNICAL CHALLENGES AND PROGRESS

Future ground station capabilities must have multiple options that the average person today takes for granted with their phone. There must be a way to handle different satellites through the use of widgets or applications that can be applied to the satellite that will then interface seamlessly into an Enterprise Ground System (EGS) backbone. The desire at COSMIAC is to take advantage of the existing communications and big data capabilities to then create the necessary infrastructure for supporting spacecraft. What was necessary was a mission to focus on. COSMIAC chose one of the existing nanosatellites the Center was building and looked at what would be required to make it EGS compatible.

The initial challenges involved the following tasks during the summer of 2017:

- Establish the application server environment for the prototype using COSMIAC organic resources.
- Install and configure the Development and Operations tool chain and document changes to the installation procedure required to adapt to Tomcat
- Install and configure GMSEC service bus. This includes installing a messaging infrastructure on top of Apache Active MQ.
- Investigate whether GMSEC can be deployed and managed in a Docker container.
- Install and configure a representative set of Multimission Satellite Operations Center (MMSOC) type applications on GMSEC with the goal being to execute a basic mission thread. We will use either NEPTUNE or COSMOS
- Investigate whether these applications can be deployed in Docker containers.

4.0 SUMMARY

Much of the initial efforts involved obtaining the software and in developing the basic skills necessary for students to become "useful." Because mature tools are available for most requirements, the students have proven to be highly productive in doing "real work" be it analysis or creating a working ground system suitable to fly a satellite.

The desired package initially was the NEPTUNE software package hosted through the Naval Research Laboratory (NRL). It has been designed from the ground up as a true multimission, site configurable command and control ground station package. The benefit for NEPTUNE is that it can do everything. The drawback for NEPTUNE is that it can do everything. What this means is that the package has a very heavy users learning curve. This is why the NRL often is interested in obtaining a significant amount of funding prior to releasing the package to users. NEPTUNE software users fund development and sustainment through the single baseline concept. The dollar amount makes this type of activity for academia and students unreasonable. To that end, the team is turning to COSMOS for the summer activities. The Hawaii Space Flight Laboratory at the University of Hawaii initiated the development of COSMOS, a system that is designed to primarily support the development and operations of one or more small spacecraft and is particularly suited for organizations with limited development and operations budget (such as COSMIAC) over the summer. COSMOS is currently being expanded into a more generic framework for heterogeneous architectures with various different kinds of nodes (assets). COSMOS is designed to be seamlessly integrated and compatible with multiple different resources (nodal architecture) or nodes such as satellites. Although not as robust as NEPTUNE, the package has less of a power learning curve and has been seen as a way ahead.

5.0 FUTURE WORK

Future activities will be related to continuing to develop common applications (as shown in Figure 5) to help create the needed interfaces that will promote EGS ideas and concepts into the capability required to help promote future missions that require a more rigid architecture.

Acknowledgments

The team at COSMIAC would like to acknowledge the financial support for students from the Air Force Research Laboratory's Space Scholars program, the Space Vehicles Directorate and the Stinger Ghaffarian Technologies Corporation.

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