34th Space Symposium, Technical Track, Colorado Springs, Colorado, United States of America
Presented on April 16, 2018

GOVERNMENT AND IC PROGRAM ADOPTION OF VIRTUALIZED SMALL SAT GROUND SYSTEMS

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ABSTRACT

For a number of years small satellites have been seen as a way to provide low cost solutions for technical demonstrations. Only recently, they have been viewed as mission-ready for government and IC programs. While the commercial world has been quicker to adopt these new platforms, government and IC programs have been slower to do so.

While small sats can be put into orbit quickly and relatively inexpensively, making them an attractive option for government and IC programs was somewhat difficult as ground system technology was not nearly as agile. Now, however, the advent of virtualized ground system environments that feature plug-and-play design for simplified setup, automation tools for lights-out operation and complete situational awareness have opened new alternatives for government and IC programs.

The migration of NASA Wallops Atmospheric Sciences Research Facility (ASRF) Small sat Ground Station (ASGS) to a highly automated ground station solution is a recent example. By migrating to a virtualized environment, NASA will increase the number of missions running through the station and avoid costs associated with added infrastructure. Here, Kratos is providing a complete end-to-end solution with configurable hardware to implement an RF link to every satellite being served. Focusing on automation, access to the satellites is now seamless during the user's time period (or pass).

While virtualized environments allow IC programs to stand up new ground stations quickly and efficiently there is still some resistance to migrating legacy systems for a number of reasons, time and effort to prepare and complete a successful migration being one of them. New programs, with no legacy systems to migrate, are willing to embrace virtualized environments. This paper discusses the NASA ASGS migration, along with some other government agency programs that are considering virtualized small sat ground stations.

WHAT DOES IT MEAN TO BE VIRTUAL?

The definition of virtualized or rather virtual is one that varies. Webster defines virtual as "being on or simulated on a computer or computer network".

For the purposes of this paper, we further define virtual as a system or piece of equipment requiring only COTS hardware in standard configurations to run. Applying this definition to ground equipment, a virtual ground system or piece of ground equipment can run on a standard server or in a cloud instance with no special or system specific configuration of the underlying hardware.

A VIRTUAL ARCHITECTURE

Before discussing virtual architectures, a quick synopsis of existing ground architectures is insightful. A traditional satellite control ground system requires basic elements to perform three general functions: Command and Control (C2), Baseband, and Radio Frequency (RF).

Legacy Architectures

The architecture shown in Exhibit 1 is generally common and known to be reliable amongst many satellite programs that are operational today.

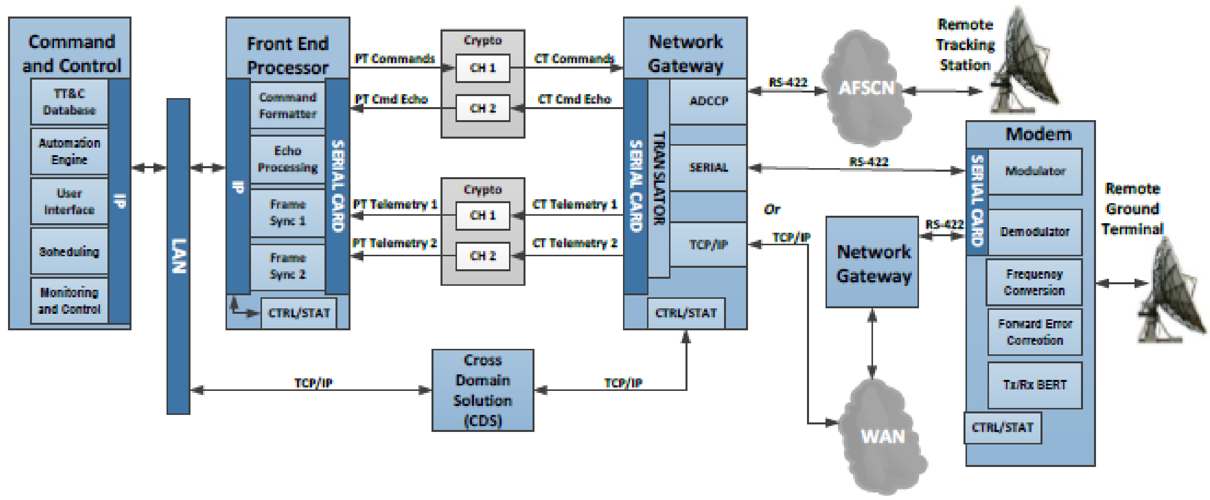

Exhibit 1: Typical Traditional Ground System Architecture[1]

As discussed in "Smallsat Ground Systems, a C2 to RF Integrated Approach"[1], the antenna systems tend to be more expensive and inflexible than the other pieces of equipment. In order to mitigate the need for every satellite program to build its own antenna farm, shared antenna systems such as the Air Force Satellite Control Network (AFSCN) were created to provide a common, distributed antenna system through which multiple Department of Defense (DoD) programs could interface for antenna uplink and downlink services. NASA's Near Earth Network (NEN) provides a similar capability for national, international, government and commercial entities. Shared antenna systems also exist in the commercial market as well with companies such as KSAT, SSC and Atlas providing services to both commercial entities as well as some national programs.

While shared antenna systems reduce the antenna expense, any mission specific hardware or systems may still be required to be co-located at the antenna site. The co-location of equipment with the antenna drives hardware investments as well as datacenter floor space*. Using edge devices, virtual architectures, and even architectures augmented with virtual solutions can see a reduction in overall operating costs.

Virtual Architectures

Virtual architectures look very similar to the "traditional ground system architecture", yet there are some major differences:

- Hardware platforms
- Data interfaces between components
- Configuration flexibility
- Cyber security considerations
- Reduction in integration labor

* Modems especially tend to require a co-location with the antenna.

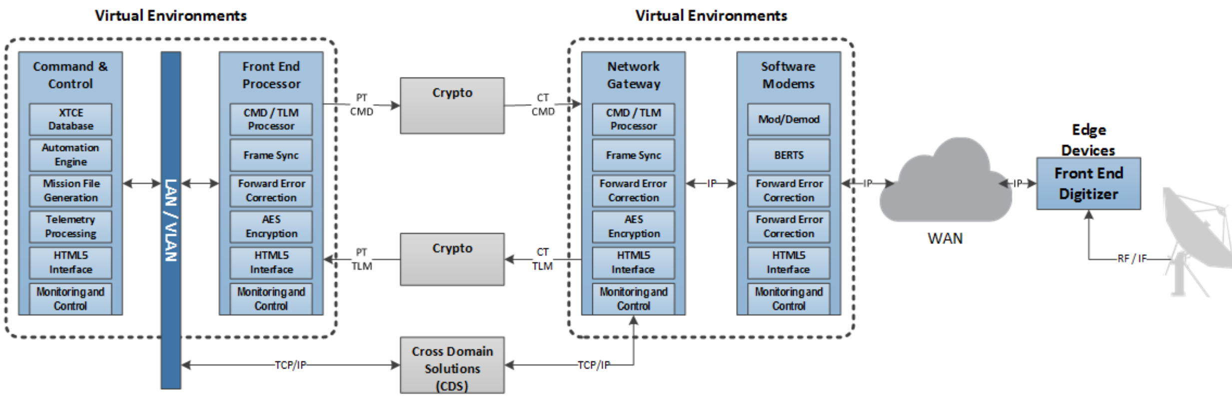

Exhibit 2: Virtual Architecture

The major change to the architecture is the idea of an edge device. In traditional architecture, the edge device or digitizing front end and modem were in the same hardware package. In a virtual architecture, the edge device is a hardware piece that could be co-located at the antenna site. Now separated from the digitizing front end, the virtual environment could host the modem (software). This lends itself to unique architectures such as distributed ground sites with consolidated processing through RF transport.

Serial communications, as shown in Exhibit 1, are common in traditional ground systems. Virtual environments by their nature do not support serial interfaces. However, by using serial to IP converters items such as legacy serial cryptographic devices can use used in a virtual environment. This is one example of how a current architecture can be augmented with virtual solutions.

One thing that changes very little between the architectures is the cyber security and distinct challenges associated with implementing cyber security in ground systems. "Cyber Security Awareness for SmallSat Ground Networks"[2] points out some of the cyber security challenges associated with small satellite ground systems, including; "… mission-unique equipment, specialized protocols, untimely patching due to configuration freezes and high regression test costs, and tight budgetary constraints."

There are a number of pros and cons to a virtual architecture and not all differences are listed here. When it comes to small satellites, many of the benefits discussed later drive a small satellite program to a virtual architecture.

A VIRTUAL GROUND SYSTEM: QUANTUM®

In this paper, we define the term "Small Satellite" as "a small satellite being nominally a satellite under 500 kilograms"[1]. Small satellites require ground systems that match the rapid rate of innovation and reduction in cost that COTS products give them on the spacecraft side. Traditional architectures are unable to meet the ever-changing needs of small satellites. A virtual ground system environment is the perfect solution for small satellite users.

quantum is the Kratos small satellite virtualized product family intended to solve small satellite ground system requirements. The quantum system consists of both narrowband and wideband offerings. The system has been designed to support missions through various stages; i.e. development, integration, launch and operations.

When developed, multi-mission and re-use were major requirements for the quantum system. By ensuring the developed ground system could be used for the current missions but also for the next several missions, the quantum system is a virtualized solution meeting the majority of user needs. While many users can use a COTS ground system out of the box, provided the system has enough configurability, there will always be those users who need something special. A virtual environment provides the flexibility for ground system developers to create custom patches to standard baselines allowing them to adapt quickly and efficiently to special customer requests.

While the majority of the quantum ground system is virtualized, there are pieces, which for different reasons, consist of hardware units. These hardware pieces are further discussed in their respective sections.

Narrowband Systems

The quantum narrowband system, in its typical configuration, consists of a digitizing front end or edge device (SpectralNet® Lite), a quantumRadio, quantumFEP (quantum Front-End Processor), and quantumCMD (quantum Command). The quantum system is fundamentally designed to support virtual environments.

The edge device or SpectralNet Lite brings a tunable range of RF frequencies, from IF up to S-band, into the digital domain. For small satellites, this is huge as they only need a single device located at the antenna and can potentially remove block converters from their budget. The SpectralNet Lite supports the Vita-49 interface to transfer the digitized data into the digital domain, i.e. to a software modem. By embracing open standards, the SpectralNet Lite could theoretically interface with any software modem (supporting the open standard) and as such is a modem agnostic edge device (the importance of this is discussed later).

The software modem or quantumRadio provides a wide range of modulation and forward error correction schemes. Currently, supporting up to 10 MHz of bandwidth, the quantumRadio is designed to handle narrowband commanding and telemetry links but can also be used for narrowband payload links. This flexibility makes it ideal for supporting a small satellite program.

The front-end processor or quantumFEP handles all of the baseband processing. Supporting a range of data protocols, the quantumFEP also provides encryption services at many different levels. Management of AES keys, their storage, and over the air rekeying (OTAR) are functional capabilities baselined into the quantumFEP.

Specifically designed for small satellites, quantumCMD provides central data management of all core command, telemetry and ground Monitor and Control (M&C) needs common to small satellite missions. For more information on small satellite command and control, refer to Kratos's complementary paper on "A Strategy for Smallsat C2, Systems, Economics, and Scaling to Meet the Challenge".

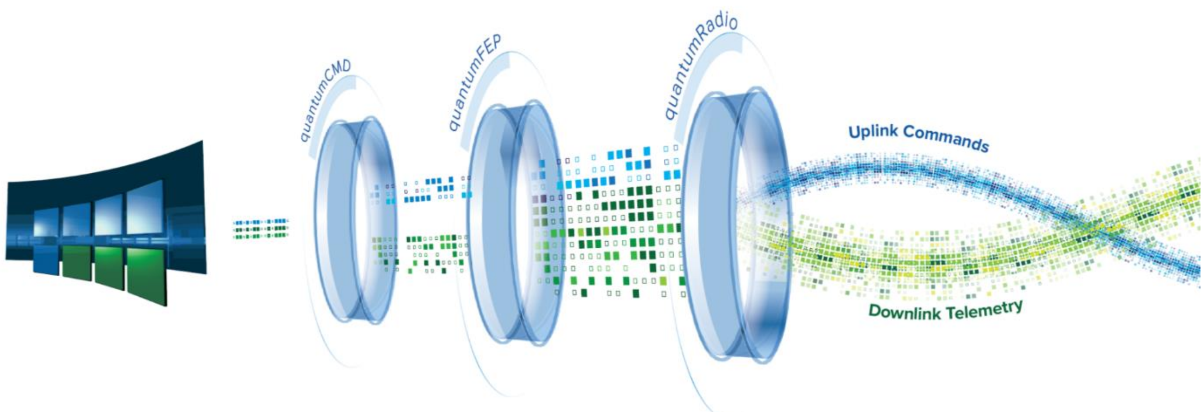

Exhibit 3: Narrowband Virtual System

Wideband System

The quantum wideband system, in its typical configuration, consists of quantumMR (quantum Mission Receiver) and quantumDRA (quantum Digital Recording Application).

As its name implies, the quantumMR is a COTS hardware solution tailored specifically to meet data rates of small satellite payload downlinks. The quantumMR can support two independent receive channels, each capable of processing up to 600 Msps, making it a power house in the small satellite receiver market. While the quantumMR is a hardware solution, it was developed with a virtual architecture in mind. By embracing standards such as Vita-49 and CCSDS, the quantumMR is highly compatible with a virtual environment.

Regarding wideband systems in a pure virtual environment, it could absolutely be done. However, the processing load to handle the downlinks would drive the system requirements such that they don't meet our definition of virtual (a virtual ground system or piece of ground equipment can run on a standard server or in a cloud instance with no special or system specific configuration of the underlying hardware). Additionally, there is a tipping point at which the cost to run a high rate wideband system virtually would cost more than a hardware unit[†].

The quantumDRA is a virtual recording application that also provides some high level processing.

Edge Devices

Edge devices will continue to play an important role in virtual architectures. Somewhere in the system, the RF signals have to get into the digital domain. Edge devices perform the function of analog to digital (A/D) and digital to analog (D/A) conversion.

As mentioned earlier, the quantum edge device (SpectralNet Lite) supports an open standard on its data interfaces. This is a key feature that must be supported by edge devices wishing to exist in a virtual environment. By open supporting standards, these devices (along with the antenna system) begin to look like nodes on a network and can be used by just about any software modem anywhere to take a pass.

ADOPTERS OF QUANTUM

NASA Wallops

In 2011, NASA and the NSF saw an opportunity to utilize the ASRF UHF System as a high-gain SmallSat Ground Station. Since that time, NASA has used the system in support of seven missions. As missions continued to increase in number, NASA began to realize the current ground system was unsustainable.

NASA then chose to retrofit the antenna site with quantum to support both current and future missions they are flying. There were several key features NASA was looking at augmenting their offering with. The quantum system solved the need of providing end-to-end connectivity between their end customers and the satellite via the ASGS site.

Connectivity between the end user and the ground site had been a challenge in the past. quantum streamlines much of the process allowing the end user access to both real-time data streams as well as achieved telemetry passes. Additionally, quantum provides user access and security features to ensure end customers only have access to their mission configurations and data sets.

The ability to automate the process of scheduling and taking a pass was of particular importance. Using quantum, NASA customers will be able to use many automation processes allowing for reduced NASA operator involvement. This automation allows for NASA to offer extended hours of operation at cost effect rates.

quantum provides a way for NASA end customers to develop system configurations without having access to the ASGS system. Any NASA customer can use an instance of quantum to develop and test against their spacecraft. These configuration files can be supplied to NASA and compatibility risk can be mitigated.

KSAT

Kongsberg Satellite Services AS (KSAT) is a commercial Norwegian enterprise, providing ground station and earth observation services. KSAT supports over 80 spacecraft including commercial, US government and international government assets. Seeing the increase in the small satellite market, KSAT launched a ground network known as KSAT-Lite.

[†] i.e. if a server farm with hundreds of CPUs or GPUs is required, the cost of the servers plus the cost to operate the server farm well exceeds the tradeoff. Additionally, datacenter floor space is greater with a server farm as opposed to a single rack-mountable unit.

KSAT-Lite is a small satellite version of the existing capacities they currently offer to their existing customer base. Of particular importance to KSAT was the ability to close the business case on KSAT-Lite (small satellite customers tend to have smaller budgets), which meant a reduction in overall operating costs. The quantum solution, a virtual architecture, was seen as a way to meet the reduction operating costs. KSAT deployed a quantum solution into the KSAT-Lite network to provide their small satellite customer a cost effective solution with a flexible and highly configurable satellite ground system.

BENEFITS OF VIRTUAL GROUND SYSTEMS

While there are the obvious benefits to virtual ground systems, like total cost of ownership, benefits such as configuration management in a multi-mission environment may not be as obvious.

Multi-Mission

A virtual architecture lends itself well to a multi-mission environment where multiple assets are trying to use the same ground system. Configuration management of ground systems for the multi-missions becomes very important. The quantum applications allow for application level configuration management. Additionally, VMs have tools (i.e snapshot and templates) that provide the ability to control configurations at the system level.

Virtual environments allow for ground network service providers to onboard customers quickly and cost effectively. End customers can develop against an instance of the virtual solution and then pass along system configuration files to the network provider. Issues such as different hardware configurations and incompatible pin outs on serial lines that plague hardware solutions do not have any impact on virtual solutions. Additionally, multiple network providers or ground networks can all share the same configuration or even the same instance of the solution (contained in either a virtual machine or container).

Several quantum users today have end customers who use their own instances of quantum that deliver configurations of quantum they have tested. These end customers are able to refine their configurations through various stages of the program, including development, integration and test, through launch and on-orbit testing.

NASA's ASGS program in the past has had customers bring their equipment to the ground site and a NASA operator would operate most if not all of the equipment for the end customer. With the quantum system they can support multiple customers and multiple missions all from a single ground site. Additionally, the operation of the system can be done remotely (from the end customer site) or in a completely lights-out approach.

Cost

As pointed out in "Flying Constellations in the Cloud"[3], cost was directly related to the size of the constellation and that operating larger constellations required significant hardware investments. Virtual solutions allow ground systems to scale exponentially with minimal hardware investments compared to hardware solutions. Additionally, cloud computing introduces architectures thatreduce the initial capital costs of ground equipment to near zero and missions or programs run entirely on operating budgets.

With virtual solutions, programs can take advantage of the scalability of the software solutions. Unique pay as you need architectures can be achieved with cloud computing. Support contracts and sparing is reduced as COTS server platforms are readily available.

With all that being said, software solutions are not free. Lots of time and effort goes into ensure virtual products work consistently and that they perform to the same level as the hardware solutions before them.

Delivery

While cost tends to be the largest driver in most programs, delivery of systems tends to be the next major pain point. With many hardware based ground systems, typical delivery time frames of three to six months (sometime longer) is not uncommon. As an example, a Kratos T400XR has a typical lead time of 120 days while a quantumRadio has an advertised lead time of less than 30 days[‡].

The ability to deliver virtual ground solutions allows for the rapid deployment of ground sites. Programs that would have taken several years can be deployed in several months. Additionally, new capabilities can be delivered either as updates or as patches to existing systems.

A virtual environment also lends itself to the testing of these deliveries in a completely new way. No longer does a program need to have a hanger-queen laying around and working. With virtual systems, a new instance of the virtual system can be spun-up in a matter of minutes and patched or updated just as quickly. Should the update or patch cause issues, the existing system remains completely un-affected. Transitions between updates can occur over time as data can be fanned out between instances. As the new system is verified and validated, the older systems can be deprecated slowly and over time.

Redundancy and Resiliency

Virtual systems are able to leverage the work going on in other software based environments, one of which is redundancy. With virtual machines (VMs), whole systems can have fail-over capabilities with systems monitoring each other and even fail-over between COTS servers. Kratos has government users who have deployed these architectures to increase the resiliency of their systems today.

The World of IT

With virtual systems, a special group of engineers no longer supports and maintains racks of equipment. The same IT department managing user workstations can manage virtual systems running on COTS hardware. The cycle of technology refresh every few years begins to disappear as software subscriptions allow a customer's system to stay up-to-date in near real time. Software subscriptions become part of an operating budget and large capital purchases of hardware systems consist of COTS servers and can be handled by IT departments.

In deploying systems into virtual environments, users of quantum interface with their IT departments to manage hypervisors, virtual machines, networking, and much more than traditional hardware solutions.

VIRTUAL CONSIDERATIONS

Crypto

While many aspects of the small satellite ground architecture have been virtualized, there are a number of things that are much more difficult to virtualize (i.e. serial interfaces). Cryptographic devices used to encrypt commanding data and decrypt telemetry data, especially in the government and IC programs, are hardware systems that are tightly controlled. Virtual systems have the ability to interface with these devices and programs requiring their use.

Interest in software based cryptographic units has increased as the use of virtual systems become more and more attractive. Technical issues, such as random number generation, and deployment issues, such as hosting a software based cryptographic in cloud based systems, have slowed the development of software based cryptographic units for ground based systems.

Many commercial customers today use commercially available AES encryption and decryption to secure their links. quantum supports commercial AES and can support secure links in cloud-based architectures. Small satellites, especially in government programs, have been seen as a way to demonstrate technology. These "tech demos" often have little to no security on the link. quantum offers a way to provide an additional layer of security to these demonstrations.

[‡] It should be noted that the T400XR has capabilities the quantumRadio does, but when it comes to the small satellite market the quantumRadio tends to provide the major of capabilities required.

Cloud Computing Services

"Flying Constellations in the Cloud"[2] provides a great overview of cloud computing and how it can be used to operate and maintain a fleet of small satellites. There are number of great benefits to operating a virtual environment in a cloud architecture. There are also a number of concerns as well, with the largest being the requirement to fully understand the implications of hosting the ground services in a cloud.

Virtualization allows for ground processing concepts like Platform As-A-Service (PAAS) offered by non-space companies such as Amazon's EC2 service or Microsoft's Azure service.

Not all cloud computing architectures are bad, though. Many benefits can be taken advantage of as long as the proper steps are taken to secure the cloud-based system.

CONCLUSION

This paper discussed how virtual environments enable commercial, government and national programs to support small satellite missions. Virtual environments allow for the deployment of new ground stations quickly and efficiently. Virtual solutions can also be used to augment existing traditional systems as well. The quantum product line is an example of how virtual environments are not only ready for missions today but also an example of how programs are actively deploying virtual ground systems.

ACRONYMS

AFSCN	Air Force Satellite Control Network
C2	Command and Control
DoD	Department of Defense
KSAT	Kongsberg Satellite Services
LAN	Local Area Network
NASA	National Aeronautics and Space Administration
NEN	Near Earth Network
NSF	National Science Foundation
SDR	Software Defined Radio
SSC	Swedish Space Corporation
VLAN	Virtual Local Area Network
WAN	Wide Area Network

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[2] Ted Vera. 2016. "Cyber Security Awareness for SmallSat Ground Networks," *Proceedings of the AIAA/USU Conference on Small Satellites*, Technical Session IX: Ground Systems, SSC16-IX-02.

[3] Chris Beam. 2017. "Flying Constellations in the Cloud," *Proceedings of the AIAA/USU Conference on Small Satellites*, Technical Session 5: Ground Systems, SSC17-V-07.

