

NASA's Space Network Ground Segment Sustainment Project Preparing for the Future

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NASA's Tracking and Data Relay Satellite System (TDRSS) ground terminals will be replaced in the 2015 timeframe. The existing terminals have been subject to many small scale upgrades and modifications since their last major refurbishment in 1994. The ground terminals, in conjunction with seven operational geosynchronous communication relay satellites, support over 20 customer spacecraft, including Terra, Hubble Space Telescope, the International Space Station and others. The terminal replacement effort, called the Space Network Ground Segment Sustainment (SGSS), will modernize the ground terminal communications infrastructure and provide new capabilities for customers. This paper describes the new architecture, some of the significant technology upgrades and the operations concepts that will enable TDRSS to provide additional services to more customers at lower cost. The SGSS will provide a flexible, extensible, scalable and sustainable ground segment that will: 1) maintain existing Space Network (SN) capabilities and interfaces; 2) accommodate new customers and capabilities, including higher data rate support and additional modulation and coding schemes; 3) reduce the effort required to maintain the ground terminals; 4) transition operations from the existing system to SGSS without disrupting services, and; 5) achieve a 99.99% operational availability for customer services. The SGSS will accomplish this by: 1) implementing an architecture using state-of-the-practice technology which enables low impact incremental upgrades; 2) simplifying the expansion process for adding ground and space assets; 3) incorporating commercial off-the-shelf (COTS) products to a very large extent, and; 4) maximizing equipment commonality. Some of the new and enhanced SGSS capabilities include: 1) the ability to easily add new transmit and receive waveforms; 2) early signal digitization for lossless signal distribution; 3) high speed digital packet switching; 4) new coding schemes, including low-density parity-check (LDPC) and turbo product codes (TPC); 5) Ka-band one-way tracking services, and; 6) data rate increases to 50Mbps for command and 1.2 Gbps for telemetry.

I. Introduction

The National Aeronautic and Space Administration (NASA) Tracking and Data Relay Satellite System (TDRSS) provides command, telemetry and tracking services to dozens of national and international customers using multiple geosynchronous relay satellites. These geosynchronous satellites, combined with networked ground terminals and terrestrial communications systems, relay data between customer mission control centers and their remote platforms.

Customer platforms take the form of low Earth orbiting spacecraft, aircraft, scientific balloons and other Earth-based transceivers. The geosynchronous relay spacecraft, called Tracking and Data Relay Satellites (TDRS) and their associated ground terminals are collectively referred to as the Space Network (SN).

Conceived in the 1970s, the TDRSS was designed to replace the worldwide system of NASA ground terminals originally installed in the 1960s to support the first NASA spaceflight missions. These old ground terminals 'looked up' at orbiting customer spacecraft as they flew overhead, limiting the contact support time. TDRSs would 'look down' at customers and, given their geosynchronous orbits, each TDRS would always be in view of its supporting ground terminal allowing near continuous relay services to customers. With this concept, the TDRSS would vastly expand coverage of low Earth orbiting vehicles, greatly enhancing the data collection capability as compared to the ground based terminals alone. The old ground terminals could be decommissioned after TDRS was put in place, saving NASA significant costs.

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The first ground terminal was installed outside of Las Cruces, NM and was called the White Sands Ground Terminal (WSGT). The TDRSS became operational shortly after the first relay satellite was launched in April 1983. The Landsat-4 mission became TDRSS's first customer in August 1983. As time passed, additional TDR spacecraft were launched and the customer base expanded significantly. Given the TDRS constellation's geometry, multiple TDRS were supported from the single WSGT.

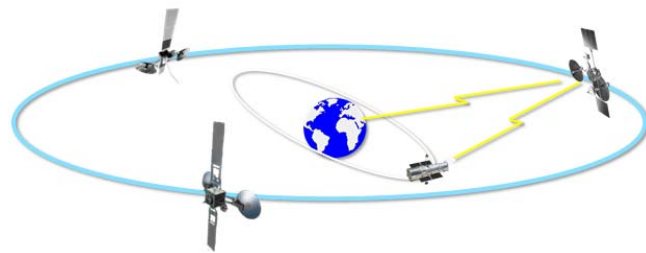


Figure 1. A Three TDRS Constellation Supporting a Low Earth Orbiting Spacecraft.

Currently, there are seven operational Tracking and Data Relay (TDR) spacecraft operated from three ground terminals supporting more than 20 unique customers. TDRSS customers include Terra, Hubble Space Telescope, Fermi, the International Space Station, several expendable launch vehicles and others. The system has been recognized as a critical national asset for US space and satellite operations. Figure 1 and Figure 2 provide a high level overview of the TDRSS concept.

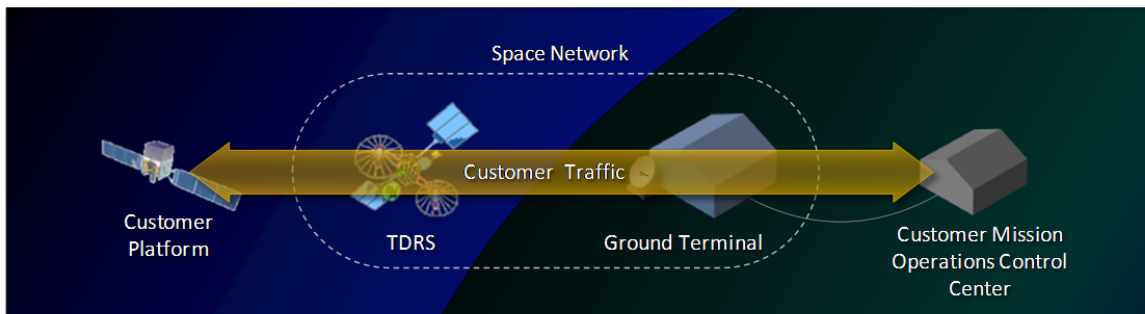


Figure 2. Customer Data Flow Through the Space Network.

II. Why Upgrade the Space Network Ground Terminals?

The existing SN ground terminals suffer from severe obsolescence and are increasingly expensive to sustain, operate, maintain and modify. Hardware, software and firmware limitations pose substantial risk to service reliability. Additionally, the ground terminal architecture itself is outdated, operations and maintenance is labor intensive and the terminal components are unable to accommodate future demands for expanded capabilities.

The last significant work on the SN ground terminals was completed in 1994 as a result of the Second TDRS Ground Terminal (STGT) and White Sands Ground Terminal Upgrade (WSGTU) efforts. These efforts resulted in the installation of a new terminal (STGT) and the modernization of the old ground terminal (WSGT). The new and upgraded ground terminals expanded TDRSS service capacity.

As service demands continued to expand, subsequent additions to the White Sands, NM ground terminals included a terminal in Guam, the Guam Remote Ground Terminal (GRGT) in 1998, and a planned future terminal in Blossom Point, MD, called the Space Network Expansion (SNE) terminal. TDR spacecraft were repositioned over the Indian Ocean and supported by the GRGT, effectively eliminating all communication gaps for low Earth orbiters allowing 24x7 coverage.

The extremely high service TDRSS customer service availability requirements, combined with the necessity to evolve to meet future needs and decrease operational costs, demands that the existing ground terminal components be replaced. The new components must be extensible, expandable, upgradable and easier to maintain and operate.

Recognizing this need to upgrade, NASA established the Space Network Ground Segment Sustainment effort, otherwise known as SGSS.

III. SGSS Goals and Objectives

To perform such a large scale upgrade which addresses the NASA and customer needs discussed earlier, NASA established multiple, detailed goals and objectives for the SGSS effort as shown in Table 1.

Table 1. SGSS Goals and Objectives.

<p><i>Implement an extensible, flexible and scalable ground terminal architecture that satisfies all customers</i></p> <ul style="list-style-type: none"> • Implement an architecture using state-of-the-practice technology which enables low impact incremental upgrades • Simplify the expansion process for adding more TDR spacecraft or additional ground terminals • Expand and improve the methods for customers to perform their service planning and control functions • Provide homogenous SGSS ground assets across all SN ground terminals • Increase customer data throughput rates and add additional support capabilities • Facilitate the terminal integration into the (future) NASA Space Communication and Navigation (SCaN) Integrated Network 	<p><i>Continue to provide existing SN functionality</i></p> <ul style="list-style-type: none"> • Monitor and control the SN flight and ground segments • Relay signals between the ground and customer platforms • Perform service planning and scheduling functions for customers • Accept and distribute customer data terrestrially using NASA-provided services and local customer interfaces • Provide radiometric tracking and spacecraft clock correlation services for customer spacecraft • Provide suites of sustaining engineering tools for flight and ground troubleshooting, trending and analysis • Train the operations and maintenance personnel • Provide built in test and customer simulation capabilities
<p><i>Reduce lifecycle cost</i></p> <ul style="list-style-type: none"> • Replace current obsolete systems • Minimize component counts and incorporate COTS products to a very large extent • Design the system so maintenance becomes routine, rather than urgent, through a combination of redundancy and graceful degradation • Maximize the efficiency of the operations and maintenance workforce • Reduce operations staffing by 60% 	<p><i>Enhance the Continuity of Operations posture of the SN</i></p> <ul style="list-style-type: none"> • Add integrated S-band capabilities to the ground terminal antennas which lack dual-band TDRS support capability • Provide prime and backup SN operations control centers • Allow for local ground terminal control capability in the event of disconnection from other terminals
<p><i>Meet or exceed the existing SN proficiency, performance and availability requirements</i></p> <ul style="list-style-type: none"> • Provide services at $\geq 99.99\%$ availability 	<p><i>Provide a low risk integration and transition into the SN</i></p> <ul style="list-style-type: none"> • Fully integrate and test the SGSS system offline, then incrementally transition TDRSs and customers to SGSS

IV. Ground Terminal Architecture and Benefits

The TDRS ground terminals provide tracking, telemetry and command (TT&C) services to the TDRS itself, as well as manage the communications payload of the TDRS which provides the actual customer services. Both the existing SN and the SGSS achieve this using the same functionality, but significantly different architectures.

As shown in Figure 3, ground terminal functions involve processing, transmitting and receiving information via Radio Frequency (RF) links to and from the TDRS, while simultaneously providing customer services through the communications payload portion of the TDRS. The upper path in the figure shows the basic functions for TDRS TT&C, while the lower path shows the customer TT&C functions.

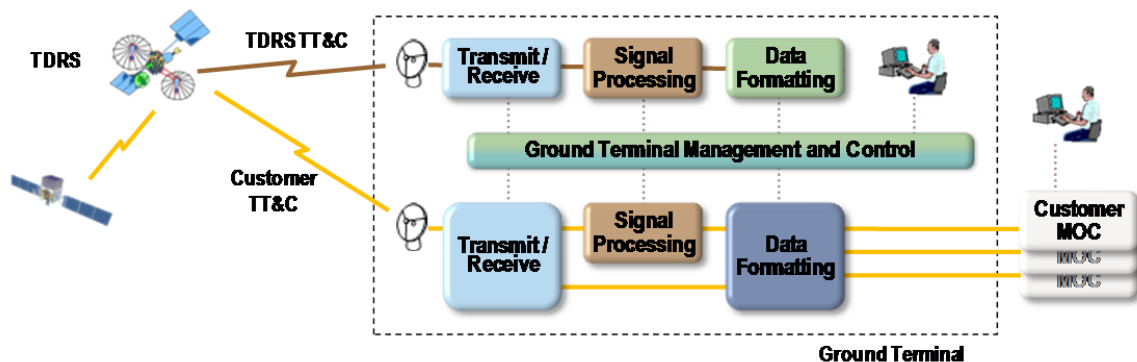


Figure 3. TDRS and Customer TT&C Data Flow.

The current SN ground terminals employ a ‘stovepipe’ architecture where signals travel through equipment strings dedicated to a particular TDR spacecraft. Although the equipment is redundant, it cannot be switched to support customers using other TDR spacecraft. This architecture limits flexibility and increases the amount of equipment needed at each ground terminal since each TDRS requires its own set of prime and redundant ground equipment.

The SGSS architecture, however, uses a pooled equipment configuration. Very little equipment is dedicated exclusively to each TDRS. Customer support equipment is selected from idle resources in a pool, services execute, and the equipment is returned to the pool available for its next use. See Figure 4 and Figure 5.

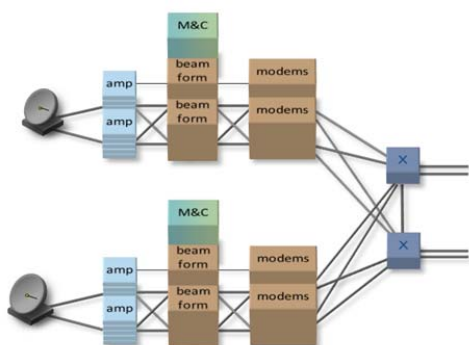


Figure 4. Current ‘Stovepipe’ Architecture.

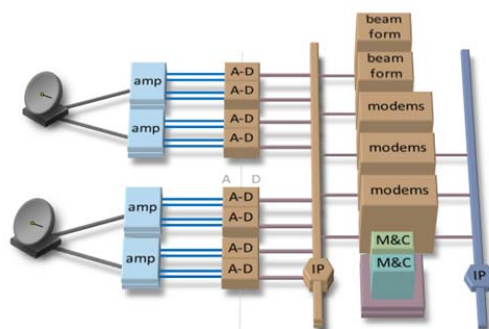


Figure 5. Future SGSS Pooled Architecture.

This pooled equipment concept permits a lower equipment count, more flexibility in configuration, more efficient hardware utilization and permits homogenous pools within and across entire ground terminals.

A. SGSS Architectural Elements

SGSS is comprised of seven distinct elements, each responsible for carrying out unique system functions. The categorization of functions into distinct elements simplifies the design process and allows improved accounting and allocation of requirements across the SGSS system.

Elements collect and distribute Radio Frequency (RF) and Intermediate Frequency (IF) signals; provide precision timing information to the entire terminal; modulate and demodulate signals; convert and process data; schedule customer, TDRS and other service and maintenance activities; monitor and control the ground terminal equipment; perform TDRS TT&C functions, including orbit determination, tracking and spacecraft health and welfare functions; provide high performance computing platforms for the ground terminal; and switch and route signals and data. A mapping of elements to the architecture is shown in Figure 6.

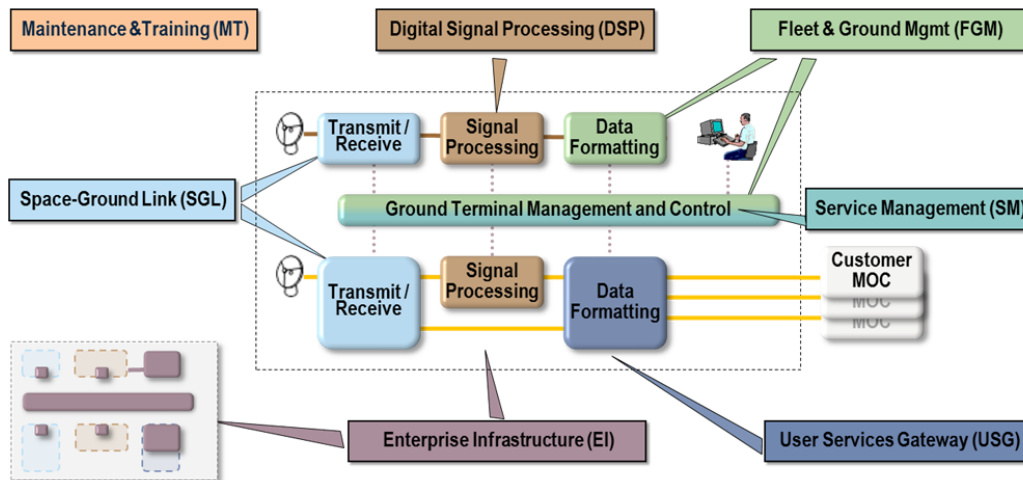


Figure 6. SGSS Elements Within the Architecture.

The seven elements interact to carry out all required capabilities of the SGSS system. Each element, function and their corresponding color codes are shown in Table 2.

Table 2. SGSS Elements.

Element	Functions
Space-Ground Link (SGL)	The SGL element provides the physical interface between the TDRS fleet and SGSS. The SGL carries customer data and TDRS TT&C signals. The SGL includes the electronics for IF/RF conversion, and the physical antenna systems for radiating and collecting RF signals. The SGL also includes precision timing and frequency references which are distributed throughout the ground terminals.
Digital Signal Processing (DSP)	The DSP element provides the signal processing functions needed to manage communication channels: extracting customer and TDRS return (telemetry) link data and processing customer and TDRS forward (command) link data. Analog-to-Digital and Digital-to-Analog conversion (ADC/DAC) functions and Sub-Band tuning / combining (SBT/SBC) are included in the DSP, as is the beamforming capability. Support for tracking services is provided by DSP by generating TDRS and customer range and Doppler measurements.
User Services Gateway (USG)	The USG element is the gateway for data services for both remote and local customers. The USG function includes support for Space Link Extension (SLE) service interfaces, IP transport, legacy support for 4800-bit blocks, tracking and clock correlation messages, customer data services (AOS/ENCAP processing, rate buffering), and customer data recording (recording and playback of return service data).
Service Management (SM)	The SM element orchestrates the delivery of all SGSS services. It provides the remote SN customer service management interfaces and local SGSS operator interfaces for managing services. SM ingests service requests and generates schedules using mission priorities and maintains knowledge of ground and space equipment availability. The SM allows automated and manual scheduling of emergency or real-time requests and distributes scheduled provisioning directives. The SM also reports scheduling metrics, including customer service accounting data.
Fleet and Ground Management (FGM)	The FGM element manages and controls the TDRS fleet as well as manages the ground terminal itself. Ground terminal management and control is isolated from customer and TT&C data wherever possible. The FGM provides distinct capabilities within a single, integrated element: TDRS fleet management and control as well as ground system management and control.

Element	Functions
Enterprise Infrastructure (EI)	The EI element provides the common software and hardware components used within the SGSS system. Unlike the other system elements, EI does not typically participate at an application level; however, some exceptions to this include enterprise messaging and providing common services such as logging. EI provides the system foundation for processing and networking support for all other elements. EI provides the computing platforms that host all application software, including all management and control processing.
Maintenance & Training (MT)	The MT Element provides independent environments for maintenance, testing, and training capabilities and is deployed within the Maintenance and Training Facility (MTF). It includes tools and equipment for analyzing and resolving failures that occur in the operational systems and the capability for testing software and hardware updates before deployment to operational systems. The MT Element also includes TDRS Simulators, Ground Segment simulators and various analysis models.

V. SGSS Benefits

The new architecture will provide multiple benefits to NASA and its customers. Benefits are realized through system simplicity, flexibility, infrastructure consolidation, fault tolerance, use of commercial standards for data transport, elimination of unique vendor lock-in by using commercial interfaces, lower operations costs and many others. Table 3 details a comparison of the current system and the benefits expected with the advent of SGSS.

Table 3. Summary of Existing SN Attributes as Compared to SGSS Attributes.

	Current System	SGSS	Comparative Benefits
TDRS Support	Each equipment string is dedicated to a specific TDRS.	Any TDRS can be supported by any antenna or terminal.	Improves flexibility, decreases equipment count.
Service Topology	Dedicated signal processing tied to individual ground antennas.	Pooled signal processing resources in each ground terminal.	Provides more services and allows more efficient equipment utilization with less hardware. Improves fault tolerance.
Ground Terminal Infrastructure	Heterogeneous systems with some IP.	Enterprise messaging, largely TCP/UDP/IP.	Improves performance and extensibility.
Signal Distribution	Analog signals largely confined to distribution within a single ground terminal.	Digital signal distribution limited only by available inter-facility bandwidth.	Unlimited signal replication. Signals easily recorded, stored and distributed.
Fault Tolerance	Multiple single point failures due to the 'stovepipe' architecture.	Multiple failure tolerance due to pooled equipment configuration.	Improves service continuity and availability, reduces required maintenance staffing.
Monitor and Control	Monolithic control computers with dedicated, unique subsystem controllers.	Distributed intelligence within and between terminals.	Improves scalability, maintainability and reduces complexity.
Customer Data	Serially switched paths internal to the ground terminal.	Routed IP, adapts to legacy interfaces at specific demarcation points.	Reliable and stable internal transport. Adapters can be removed as interfaces evolve.
Software Architecture	Monolithic, tightly coupled, hardware dependent Ada/VMS.	Distributed, loosely coupled Service Oriented Architecture using modern languages: C, C++, C#, Java, Linux, Windows.	Improves maintainability and portability. Allows access to an expanded maintainer base.
Enterprise Management	Multiple, independent, dispersed management domains.	Single enterprise concept, using industry standard tools and protocols.	Improves system visibility and availability, reduces required staffing.

	Current System	SGSS	Comparative Benefits
Processing Platforms	VMS-compliant (VAX, Alpha).	x86 compatible (x86, x86-64).	Large vendor base, extends longevity.
Modem Technology	Hybrid analog/serial digital systems with serial baseband processing. Proprietary platforms limit upgrade possibilities.	Pure digital modulation and demodulation over IP, IP distribution at baseband, telco-standard μ TCA platforms, FPGA upgradeable waveforms.	Extensible at all levels – software, firmware and interfaces. Enables straightforward customer waveform and/or device insertions.

A. SGSS Technologies

SGSS will realize its goals and objectives by using a new, “state-of-the-practice” architecture. Since the development effort has constrained cost and schedule targets, relatively mature technologies are being used to minimize risk.

Some key technologies critical for the success of the system are the Digital Fabric infrastructure, μ TCA usage, virtual machines and radial combiners. Each will be discussed in following sections.

1. Digital Fabric

The most significant technology being employed in the terminals is a pervasive digital fabric. This digital fabric, using multiple 10GbE segments, carries information throughout and between the ground terminals. The fabric is segmented into two separate entities, one carrying digitized IF data and the other carrying packetized baseband data, all in IP form. Digitized IF data will be packetized using the VITA 49 Radio Transport Standard in IP packets.

Components of SGSS will operate in a “publish and subscribe” manner to gather and disseminate data to and from various components. For example, a customer receiver would subscribe to a digital IF data stream created by a sub-band tuner on the IF digital fabric. The receiver would then digitally demodulate the data and publish the packetized customer telemetry on the baseband fabric. Data formatters would subscribe to the demodulated telemetry data, perform any required conversions and send the data out to the customer on external networks.

a) SN Analog vs. SGSS Digital

The existing ground terminals largely use analog signal processing and distribution systems. Telemetry signals flow in analog format up to demodulators, where they are converted to digital signals. Similarly, command signals are converted from digital form to analog form in modulators, flowing as analog signals from that point forward. Analog systems are subject to signal loss, interference and require expensive cabling, waveguide and switches.

The SGSS architecture digitizes the entire TDRS downlink immediately after receipt and downconversion from K-band to L-band at the ground antenna. Customer and TDRS telemetry is put into VITA 49 packets which flow to digital demodulators. For command signals, the information is maintained in its digital form as long as possible and is converted to analog just before transmission to the TDR spacecraft.

Digitization allows for lossless distribution, infinite replication and wide use of open-standard infrastructures.

b) “Enterprise Class” Digital Signal Fabric

A precise time-tag is applied as each signal is digitized and placed into digital IF packets. The time tag, accurate to 10ns, enables superior jitter performance, high-fidelity reproduction and signal arraying. The digital fabric is capable of being connected between ground terminals which allows multiple-terminal access to data, eliminating single points-of-failure. The fabric is also capable of being scaled to accommodate additional consumers, higher bandwidth and more processing systems.

Customer and TDRS commands are accepted as either baseband data and/or digital IF signals. Each forward service signal is modulated in digital form, enabling cross-site uplink aggregation, and is combined into a consolidated uplink for transmission to the TDRS and relay to the customer platform. Figure 7 shows the digital fabric in the SGSS architecture.

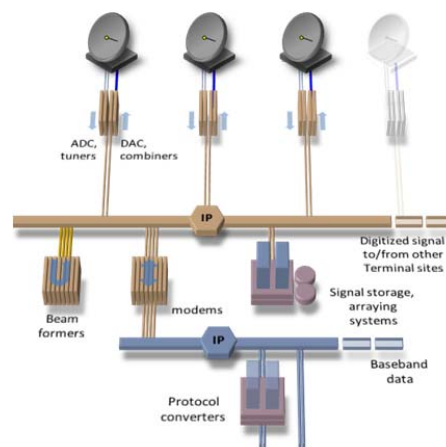


Figure 7. SGSS Digital Fabric.

B. Hardware Interfaces

SGSS plans to use μ TCA components for the majority of the DSP element, including the analog-to-digital converters, modems, beamformers and processors. The μ TCA architecture is also employed for USG local interface functions.

The use of μ TCA open-standard technologies will provide commercially available standard physical and electrical interfaces which helps prevent unique vendor lock-in and saves money due to the low unit costs for the chassis, power supplies and processing cards. Figure 8 and Figure 9 show representative μ TCA chassis and component cards which populate the chassis.

Figure 10 demonstrates the size reduction for modems and beamformers as compared to the current system. SGSS will accomplish more functionality in 1½ equipment racks versus the 24 needed in the current system.



Figure 8. μ TCA Chassis.

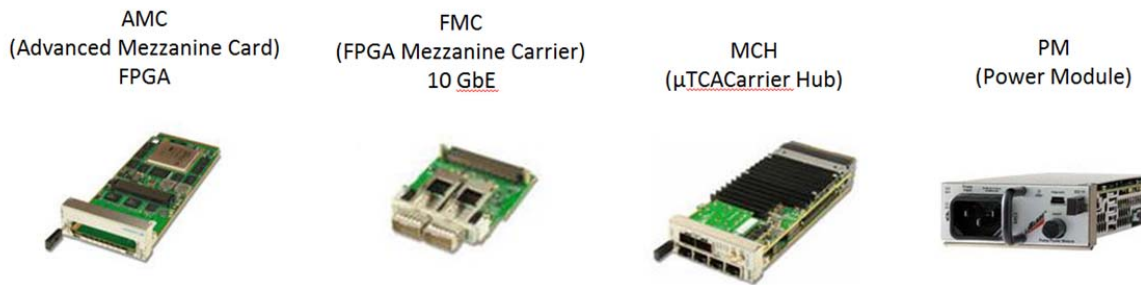


Figure 9. μ TCA Components.

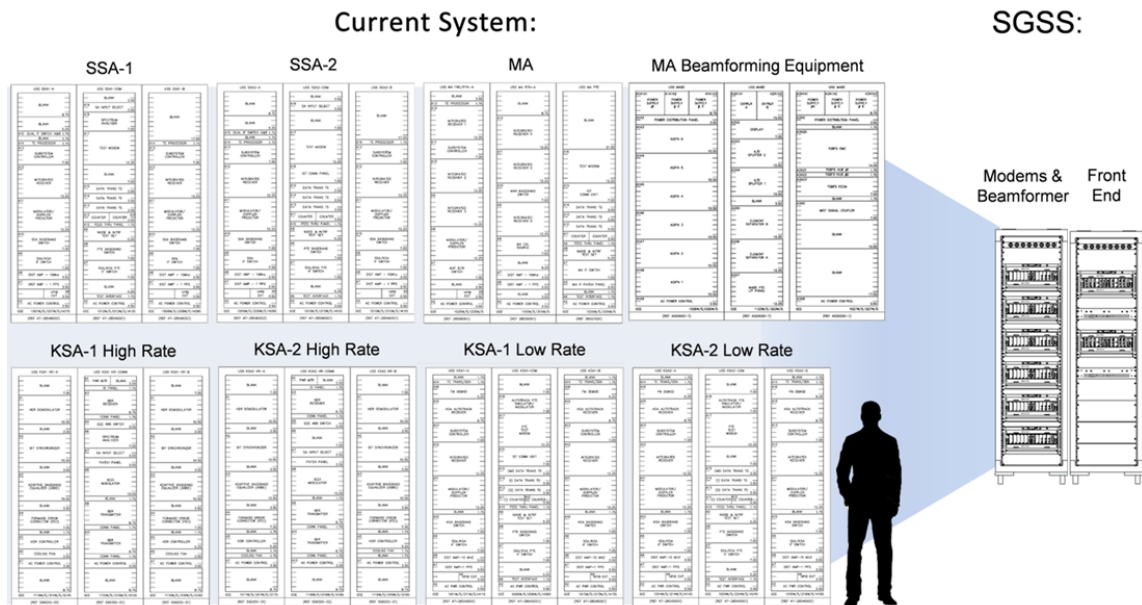


Figure 10. Size Reduction Projection for the DSP Element.

C. Virtualization

SGSS will extensively use Virtual Machines (VMs). Virtualization isolates applications and the operating system from the physical platform. To the operating system (OS), a VM appears as a physical machine and emulates hardware components, allowing the OS to run in its native mode. Virtualization enables application and OS longevity, provides opportunities for transparent technology refreshes and optimizes machine utilization. Today's VM performance approaches a dedicated machine's physical performance, allowing multiple VMs to run on a single platform with little to no performance impact. VMs also provide additional measures of security, since applications can be isolated.

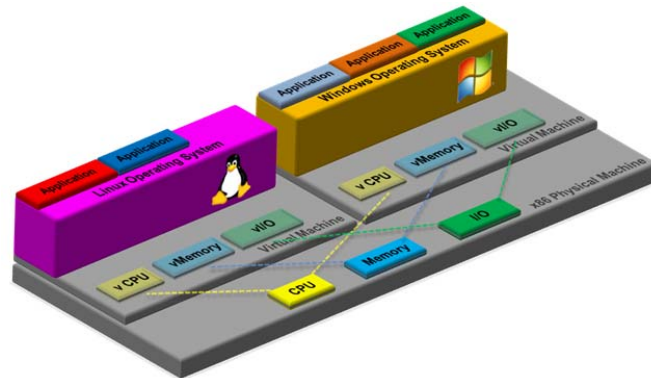


Figure 11. A Single Platform Running Two Virtual Machines.

D. Ku-Band Uplink – Radial Combining and Solid State Amplifiers

Current signal amplification for the TDRS uplink is performed using Traveling Wave Tube Amplifiers (TWTAs). These amplifiers are large, bulky and consist of vacuum tubes which are becoming less available and more expensive to replace. SGSS plans to use multiple, lower power Solid State Power Amplifiers (SSPAs) for the TDRS uplink. The output of the SSPAs will be joined in a radial combiner to achieve the necessary uplink power.

The use of SSPAs will result in a significantly reduced equipment footprint, increased redundancy, better fault tolerance and permits graceful degradation in the event of individual amplifier failures. The technology also allows easier maintenance and logistics processes and permits a 'hot swap' capability without interrupting the uplink.

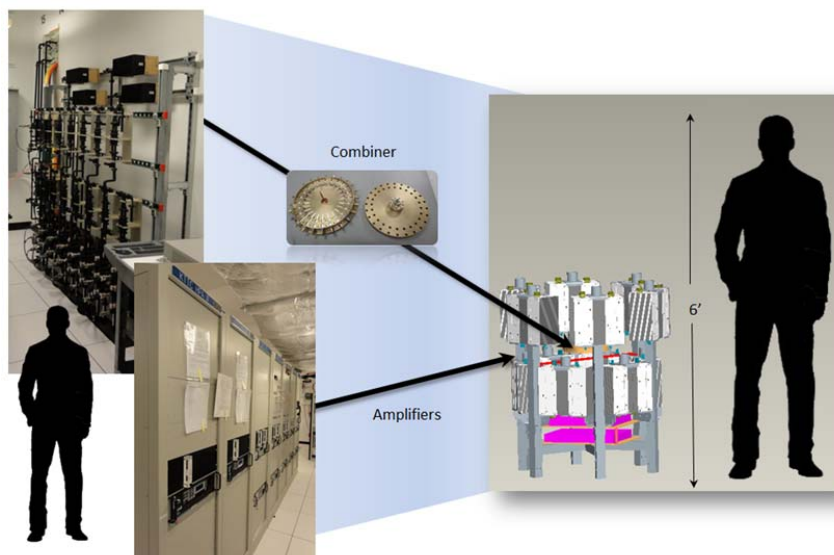


Figure 12. Ku-Band Uplink Power Amplifiers and Combiner Size Reduction.

VI. New Capabilities Afforded by SGSS

In accordance with the SGSS goals, the new ground terminal will build in capabilities above and beyond the current capabilities. Enhanced operator visibility into the ground terminal status heightens situational awareness. Service scheduling algorithms will be optimized to use resources more efficiently and increase service availability. A wide variety of customer scheduling interfaces will allow compatibility with existing scheduling interfaces, eliminating the need for customers to change their systems. Other scheduling interfaces will allow web-based, CCSDS and bulk, file-based scheduling for customers.

Additional signal coding and modulation schemes will be introduced, including low-density parity-check (LDPC) and turbo product codes (TPC), along with 8-phase Shift Key (8PSK) modulations. Backwards compatibility with existing SN coding and modulation schemes will be maintained.

Data rate throughput will be increased to 1.2Gbps for return services and CCSDS services will be natively available.

VII. Operations Concept

A. Operations

For all missions developed at the Goddard Space Flight Center (GSFC), a driving principle for operations preparation is to “Test as you fly, fly as you test.” To ensure that the deployed system reflects the needs of the operators, the SN operations team has worked closely with the SGSS design team to ensure that the design includes operators’ perspectives.

The SGSS team has produced an Operations Concept (Ops Concept) document as part of the Phase A development activities (Phase A precedes preliminary design). The Ops Concept document has been crucial in helping to define high-level requirements for the Systems Requirements Review, and will be used to define lower level requirements in preparation for the Preliminary Design Review. This philosophy will continue into the verification phase as specific tests will be designed to ensure operations compliance, with test scenarios being developed based on operational scenarios described in the Ops Concept.

Scenarios in the Ops Concept will include both nominal scenarios (e.g., TDRS telemetry processing and command generation, TDRS scheduling and configuration for operations support) and contingency scenarios (e.g., non-acquisition of a customer platform, temporary loss of remote scheduling capabilities). These scenarios, as well as the existing operational experience, will drive the development of operation procedures and provide the basis for the development of training material.

The Ops Concept is designed around the concept of maximizing the extensibility, scalability, flexibility, and maintainability of the system, while reducing the operational cost of the SN. With a goal of reducing the operational staff by 60%, the architecture must support an Ops Concept that will permit such a large reduction. To achieve a staffing reduction while maintaining a very high level of availability (99.95% in 2011 for over 176,000 hours of service), the new system will be designed to increase the efficiency of individual operators as well as the overall team. GUI displays will be operator friendly to reduce human error and will be easily configurable. Multiple levels of automation will be designed into the system, which will allow operators to “dial up” automation as they become more comfortable with the ground system. By including the ability to incorporate higher levels of automation, additional reductions may become possible in the future.

System maintenance will undergo a dramatic paradigm shift with the SGSS system. In maintaining the current ground terminal, most system maintenance occurs at the site. A large staff of personnel is required to repair hardware when a component fails since they must be able to accommodate failures 24x7 and be trained to repair a wide range of hardware. The maintenance philosophy for SGSS relies on a much smaller pool of people. To achieve these personnel reductions, on-site repair of the hardware is no longer the primary mode of repair, but rather the hardware is designed to be easily replaceable upon failure, with the failed unit returned to the vendor for repair. Hardware repair agreements will be pre-negotiated with vendors in advance, helping to minimize costs.

When a failure occurs during a service, the system will configure and switch to other units autonomously, with minimal impact to the ongoing service. Since equipment is pooled, the pool depth can accommodate many failures without suffering any significant impact. The pool depth, as well as the number of shelf spares, will be determined by analyzing component reliability while considering the overall system availability requirement. Repairs will not have to occur during nights and weekends on an emergency basis, but rather can be carried out during normal business hours, allowing a significant reduction in staffing levels.

B. Transition

A guiding requirement, as described in the SGSS Statement of Work is "...any changes made by the Contractor to SN ground facilities and systems shall not adversely impact the ongoing operations of the SN." The complete transition to the new system must occur while maintaining the high levels of service demanded by SN customers.

The verification of the system has been grouped into five distinct levels. Levels 1-3 will test components and subsystems, while Level 4 testing involves testing multiple interconnected subsystems as a system. Level 4 testing will occur at the prime contractor's development facility in Scottsdale, Arizona. Level 5 and 6 testing are system tests run at field sites (Blossom Point, MD; White Sands, NM; and Guam). The goal of Level 5 testing is to verify and validate system level and external interface requirements at each site in preparation for Level 6 activities. During Level 5 testing, the use of simulators is minimized to ensure the SGSS configuration is as close to an operational configuration as possible. The test team will perform shadow (passive) testing of TDRS spacecraft for validation of command/control prior to going live with a TDRS. Shadow testing will also be used to validate customer services.

Level 6 testing is the final test level and is the last step in the transition to operations. Level 6 testing will involve final validation of external ground interfaces, TDRS command/control functions and customer services using both simulators and actual customers. A Test Readiness Review (TRR) will occur prior to testing each segment, with a 'segment' being defined as a specific combination of a ground antenna, TDRS and the SGSS equipment at a ground terminal. An Operational Readiness Review (ORR) will occur after the completion of each Level 6 test. Upon completion of the ORR for each segment, the segment will be fully functional and schedulable for routine use. A contractual final acceptance review (FAR) occurs after all segments have been transitioned into operations.

A particular challenge for SGSS is that a number of TDR satellites must continue to be supported while the transition is on-going. Some TDR satellites are in a stored state, while others are actively supporting customers. Regardless of the satellite state, separate ground antennas are required to control each satellite at all times. Because of this requirement, SGSS cannot take more than two antennas at White Sands and one antenna at Guam out of service for the upgrade at a time. Because Blossom Point is a new facility and is not supporting any TDRSs, it is not subject to this constraint.

The current schedule, shown in Figure 13, calls for the first transition in 2014 with all remaining segments finishing transition in late 2015.

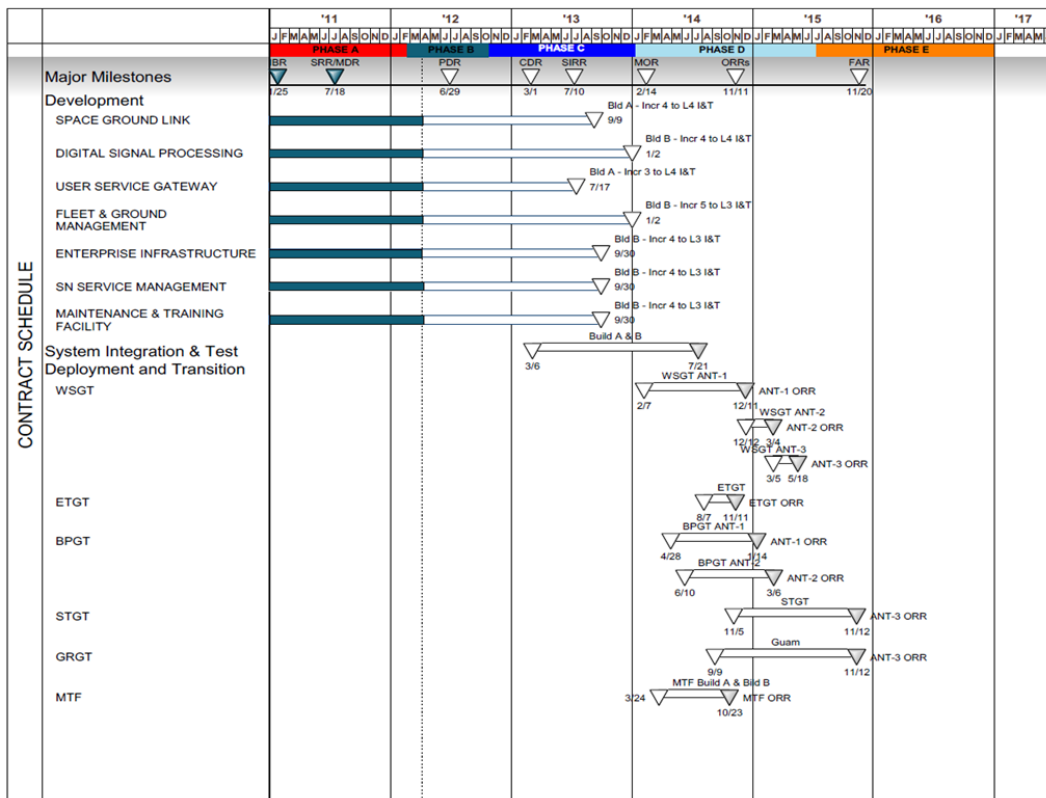


Figure 13. SGSS Schedule.

VIII. Conclusion

The new SGSS architecture will allow cost-effective technology refreshes and upgrades due to its readily extensible architecture and use of commercial and open-standards. The system modularity, extensibility and application isolation supports non-disruptive upgrades, enabling a near continuous refresh cycle without interruption to customer or TDRS support. The SGSS network is also scalable, allowing additional capacity to be easily added. The use of software-based modems, hosted in field programmable gate arrays (FPGAs), easily allows the introduction of new customer waveforms. The inclusion of CCSDS Space Link Extensions combined with comprehensive service management tools presents SGSS as a mission solution for a wide variety of existing and future customers. New modulation and coding schemes allow greater data volume transport with extremely low latency and better spectral efficiency.

The SGSS will provide a marked change from the current labor-intensive, obsolete system now in use by the SN. The SGSS is being designed for an operational life of at least 25 years. The new design will allow a significant reduction in operations and maintenance costs, while providing operators with a greater degree of insight into the status of the TDR spacecraft, ground hardware and on-going customer services. Ultimately, the maintenance and operations savings achieved by SGSS will enable NASA to support customers in a more cost effective manner.

Appendix A Acronym List

10GbE	10 Gigabit Ethernet	PSK	Phase-Shift Key
8PSK	8 Phase Shift Key Modulation	RF	Radio Frequency
ADC	Analog-to-Digital	SBC	Sub-Band Combining
AMC	Advanced Mezzanine Card	SBT	Sub-Band Tuning
AOS/ENCAP	Advanced Orbiting System/Encapsulation	SCaN	Space Communication and Navigation
BPGT	Blossom Point Ground Terminal	SGL	Space Ground Link
CCSDS	Consultative Committee for Space Data System	SGSS	Space Network Ground Segment Sustainment
CDR	Critical Design Review	SIRR	System Implementation Readiness Review
COTS	Commercial Off-the-Shelf	SLE	Space Link Extension
CPU	Central Processing Unit	SM	Service Management
DAC	Digital-to-Analog	SN	Space Network
DSP	Digital Signal Processing	SNE	Space Network Expansion
EI	Enterprise Infrastructure	SOA	Service Oriented Architecture
ETGT	Extended TDRSS Ground Terminal	SRR	System Requirements Review
FAR	Final Acceptance Review	SSA	S-band Single Access
FGM	Fleet and Ground Management	SSPA	Solid State Power Amplifier
FMC	FPGA Mezzanine Carrier	STGT	Second TDRS Ground Terminal Tracking and Data Relay Satellite
FPGA	Field Programmable Gate Array	TCP	Transmission Control Protocol
GRGT	Guam Remote Ground Terminal	TDR	Tracking Data Relay
GSFC	Goddard Space Flight Center	TDRS	Tracking Data Relay Satellite
GUI	Graphical User Interface	TDRSS	Tracking and Data Relay Satellite System
I/O	Input/Output	TPC	Turbo Product Code
IF	Intermediate Frequency	TT&C	Tracking, Telemetry and Commanding
IP	Information Protocol	TWTA	Traveling Wave Tube Amplifier
ISS	International Space Station	UDP	User Datagram Protocol
Ka	Ka-band	USG	User Services Gateway
KSA	K-band Single Access	VAX/VMS	Virtual Address Extension/Virtual Memory System
Ku	Ku Frequency Band	VITA-49	VITA Standards Organization Radio Transport Standard 49
LDPC	Low-density Parity-check	VM	Virtual Machine
M&C	Monitor and Control	WSGT	White Sands Ground Terminal
MA	Multiple Access	WSGTU	White Sands Ground Terminal Upgrade
MCH	μTCA Carrier Hub	x86	The family of instruction set architectures based on the Intel 8086 CPU
MDR	Mission Definition Review	μTCA	Micro Telecommunications Core Application
MOC	Mission Operations Center		
MOR	Mission Operations Review		
MT	Maintenance Training		
MTF	Maintenance and Training		
NASA	National Aeronautics and Space Administration		
ORR	Operational Readiness Review		
OS	Operating System		
PDR	Preliminary Design Review		
PM	Power Module		

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