NASA SPACE COMMUNICATIONS AND NAVIGATION: ONE NETWORK EVOLUTION

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1. Abstract

The NASA Space Communications and Navigation (SCaN) Program is responsible for providing the essential connectivity to robotic and human space explorers. The missions relying on SCaN range from suborbital and balloon missions to those traveling beyond the edge of the solar system. The demands for communications and navigation services enabled by SCaN (and its affiliated partners) are projected to increase and outpace the current network capacity. At the same time, the Agency finds itself surrounded by a burgeoning commercial space marketplace, technological advancement, and other government agencies that share common interests in space resiliency, robustness, and performance. As a result, SCaN has begun pivoting toward commercial services and collaborating with partners to close capacity and capability gaps. Given these growing demands of the Agency there is increasing need for multi-network solutions. Future mission concepts will rely on both government and commercial capabilities, both Near Space Network capacity and Deep Space Network capacity. Integrating these diverse support services together from a technical, programmatic and implementation standpoint will be key to meet the growing needs of the future. To accomplish this, a more substantive shift is required, and SCaN is reshaping itself to be a customer-centric, service-oriented, high-performance leader in the space communications community. This paper outlines the SCaN One Team, One Mission, One Network approach, and provides a vision for future mission community experience that includes streamlined mission commitment interfaces and clear processes, dynamic network scheduling and load balancing, and higher efficiency data transport and delivery through the integration of cloud infrastructure and services.

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2. Introduction

For nearly two decades, NASA's Space Communications and Navigation (SCaN) Program has provided essential connectivity for a diverse range of mission operated by NASA and its partners. Even as the broader space ecosystem has transformed around it, SCaN still operates much as it did when it was first stood up to consolidate NASA's various space communication services under a single umbrella. Two of its primary services, the Deep Space Network (DSN) and the Earth proximity space relay support provided by the Near Space Network (NSN) though its constellation of Telemetry Data Relay Satellites (TDRS) were first designed in the 1960's and 1970's, respectively. The infrastructure within these legacy systems has been maintained and upgraded, but in some cases is being utilized well beyond its anticipated useful life. Furthermore, in support of these networks, SCaN often continues to run scheduling and loading analyses with previous-generation technology.

In parallel with the challenges raised by these aging systems and concurrent capacity limitations, SCaN's forward projections indicate rapidly growing demand across all SCaN networks. This is poised to generate an imbalance between network capacity and mission requirements. Indeed, while SCaN has successfully supported its full range of customers at a high level with current approaches, there have been individual instances of mission challenges, and such concerns and conflicts are poised to become more frequent. A change in how SCaN does business is required to ensure it maintains its position as the world's leading space communications provider.

Recognizing this, SCaN is adopting a new approach that will maximize flexibility and collaboration within our networks, while positioning us to fully take advantage of transformations in the broader space ecosystem. It is a time of tremendous change, but also opportunity. SCaN's leadership is working to restructure the program through a "blank page" method that asks – how can we best position ourselves to make the next 20 years as successful as the last 20?

The output of this effort is our new One Team, One Mission, One Network approach. This reorientation of the program towards excellence is unfolding across three North Stars which define SCaN's core functions. 1) To provide reliable, robust, and resilient space communications and navigation capabilities to enable safe execution of NASA missions. 2) To architect, develop, and partner to deliver the space communications and navigation capabilities of the future. 3) To demonstrate world-class leadership through responsive engagement with communications and navigation stakeholders inside and outside the Agency. The organization has already begun to enact this future vision of SCaN's operations while continuing to explore critical guidance, ideas and challenges which will undergird the implementation of this revised strategy.

3. SCaN's Current Status

Rapidly Growing Demand

SCaN provides essential connectivity to robotic and human space explorers whose domain ranges from suborbital and balloon missions to beyond the edge of the solar system. The demands for communications and navigation services enabled by SCaN (and its affiliated partners) across all these mission types are projected to increase exponentially. As NASA's science and exploration capabilities mature, the instruments, payloads, and operational needs are driving significant increases in data volume demand, up to 10's of Terabits per day. For context, this is three orders of magnitude beyond the data volume that the Hubble Space Telescope (HST) sends back, itself considered a data-intensive mission at the time of its launch. Given the stable or in some cases declining projections for the capacity of SCaN's current networks, this demand increase represents a real challenge to mission support.

In keeping with this data demand trend, several recent and upcoming missions represent some of the highest-data demand robotic missions in NASA history. The James Webb Space Telescope (JWST) is an orbiting infrared observatory that is creating incredible science insights and imagery of distant stars, dust clouds, and planetary systems. It orbits nearly 2-million miles away at the Sun-Earth L2 Lagrange point and utilizes the DSN for downlinking data. It is a high data rate mission transmitting at 28 Megabits per second (Mbps) over a Ka-band downlink, totaling 270 Gigabits of science data per day. JWST is now the highest-demand regular DSN user, requiring at least one four-hour communication contact every twelve hours, and frequently exceeding that.

The Near Space Network (NSN) is similarly facing new demands. The Plankton, Aerosol, Cloud and Ocean Ecosystem (PACE) is an Earth-observation mission launched in 2024 that is offering critical information on the planet's atmospheric and oceans. It produces approximately 5 terabits of data per day that is downlinked directly to Earth ground stations, a data volume so high that it has required novel cloud approaches to support. Those same approaches will be strained further by the upcoming NASA-Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR) mission, which is projected to require 26 terabytes of data be downlinked per day.

For these missions, SCaN has adopted current network technologies or made innovations that have enabled the current network to provide critical support. However, these robotic missions represent the proverbial tip-of-the spear of a new generation of missions that use higher resolution instruments and data processing and are poised to overwhelm current network capacity. While current networks can accommodate a handful of these missions, if high-throughput missions become the norm without changes to SCaN's approach, it may place NASA in a position where the data throughput capacity of its networks becomes the limiting factor for space mission science.

Legacy Technologies Leading to Emerging Challenges

The technologies underlying the SCaN's networks is in many cases decades older than SCaN itself. For example, NASA relies on a constellation of Telemetry Data Relay Satellites (TDRS) for Near-Earth Proximity Relay, an architecture established in 1973 to provide continuous service to LEO missions including the emerging Space Shuttle Program. Operations began with the deployment of TDRS-A in 1983, and even the newest space-segment elements are nearly a decade old. There is no current expectation of space segment replenishment. Moreover, the overall architecture of the TDRS system remains—with limited exceptions—largely the same as it was first conceptualized over 50 years ago.

Recent events impacting TDRS demonstrate how future sustainment challenges may end up having serious impacts on missions. Typhoon Mawar made landfall on Guam on May 24, 2023 causing catastrophic damage to NASA's Guam Remote Station (GRS), one of three ground stations that support the TDRS constellation. Impacts to GRS temporarily created a Pacific zone of exclusion, impacting not only robotic missions, but also communication support for the crewed International Space Station and visiting vehicles. While the cause was different than the expected decline of the current TDRS constellation, this offered a preview of the serious impacts that diminishing TDRS space and ground segments may have on critical missions.

Major components of the DSN, a network of large-diameter antennas that support missions beyond Earth orbit, are similarly aged. Key elements like the 70-meter antennas used for supporting missions like the Voyager space probes are well into their sixth decade of service, and require meticulous sustainment efforts to counter structural fatigue, corrosion, and wear. There are ongoing upgrade efforts, including the ongoing DSN Aperture Enhancement Project (DAEP) which is providing the DSN with additional apertures and increased capabilities for Ka-band, and DSN Lunar Exploration Upgrades (DLEU) which are increasing throughput and enabling concurrent antenna operations in multiple frequency bands. However, network constraints continue to mount. Indeed, contention for DSN assets and support challenges during the Artemis I mission in November 2022 offer a first indication of how challenging this new generation of high demand missions may be for DSN.

The Artemis program represents the first time since the 1960's that DSN assets will be used to support human spaceflight, and Artemis will be draw upon them with unprecedented intensity. These crewed missions to the cislunar region are inherently high demand, with each successive missions anticipated to require more support. Requirements include redundant 34-meter Beam Wave Guide (BWG) antenna support on a 24/7 basis. Despite efforts to achieve this support posture, core mission communications for Artemis I were at times compromised. The NASA Office of the Inspector General (OIG) released a report attributing the loss of in-flight communications to hardware and process issues with the DSN that were primarily caused by deferred maintenance and aging hardware [1].

Separately, the high network demand during Artemis I led to serious contention for the use of ground assets with robotic science missions. These were compounded by the support of 10 secondary payload "CubeSats," most also supported by DSN, and five of which experienced disruptions that required further antenna time. To accommodate this extraordinary network demand the JWST was forced to switch to lower-data usage science. At longer timescales, this mitigation would have prevented their team from meeting mission requirements. Other missions were also forced to forego planned antenna time, and maintenance was deferred that would otherwise have been undertaken. A separate OIG audit of these circumstances found that "NASA's DSN is currently oversubscribed and will continue to be overburdened by the demands created by an increasing number of deep space missions" [2].

4. Becoming One Network: Unifying SCaN Operations

These growing demands of the Agency have created a need for new approaches to multi-network operations that unify the various networks at SCaN as one coherent and reliable entity. Part of this will require a unification of processes. Scheduling and analysis are conducted in radically different ways by the DSN and the NSN's ground and TDRS space relay segments. Missions must learn and proceed through multiple processes in parallel as part of the mission engagement experience, diminishing efficiency and creating a sense that SCaN is a series of networks instead of one coherent entity. This requires effective integration of assets. In this context, integration represents a drive for seamless cross utilization of networks, not a physical combining of networks. Our “One Network” principle calls for us to smooth out these differences, ensuring all users can operate from the same rulebook, and eliminating inefficiencies which may ultimately diminish or endanger mission support.

Another part of the “One Network” approach is unlocking direct cross-network support. Our team is already taking first steps in this direction, as demonstrated by the DSN’s recent contingency support of NSN assets impacted by service outages at GRS. Due to the impacts of Typhoon Mawar and work necessary to complete recovery efforts, GRS continues to intermittently experience service outages. These outages have sometimes occurred in parallel to reliability challenges at the Australian TDRS Facility (ATF), a backup facility for GRS TDRS support. The parallel site service challenges of GRS and ATF have the potential to result in adverse impacts to NSN users of both stations. When this happens, it puts two separate TDRS “adrift” without tracking and command support.

Recognizing the significant challenge this represents for the NSN, the DSN team has stepped in to support and ensure these TDRS receive S-band station-keeping support. In doing so, personnel at NASA's Jet Propulsion Laboratory (JPL) and the Canberra Deep Space Communications Complex (CDSCC) have provided genuinely critical leadership and capabilities to TDRS users. This is the first time that the DSN supported controlling a TDRS satellite for multiple months. This work using one SCaN network to support another created new robustness and resiliency for the program, embodying the “One Network” principal towards which we aspire.

The integration between the NSN and DSN will become even more critical with the emergence of a new NSN capability; Lunar Exploration Ground Sites (LEGS). Currently, most ex-GEO missions are supported by the DSN. However, in support of the Artemis missions and increased activity at the Moon, NASA has initiated the LEGS project which will provide “18-m class” direct-to-Earth (DTE) support at multiple new ground stations, with sites dispersed globally. LEGS Sites 1-3 will be government-owned/contractor-operated (GOCO) sites with a primary, but not exclusive, function to support the 24x7 coverage requirement of the Artemis Gateway mission. Site 1 will be located at NASA’s White Sands Complex, with Sites 2 and 3 are being pursued in partnership with the South African National Space Agency (SANSA) in South Africa and the Australian Space Agency and Commonwealth Scientific and Industrial Research Organization (CISRO) in Australia. Additional ground station locations (Sites 4-6) and services will be determined based on the outcome of an active NSN Services procurement process, with the commercial sites and service offerings are anticipated to include capabilities for S, X, and Ka-band transmit-and-receive services.

Nominal LEGS services will be active in advance of the Gateway Launch Readiness date and the Artemis III mission. This will help address anticipated capacity shortfalls and alleviate pressure on the DSN 34-m assets, allowing them to focus on deep space mission support. However, it can only succeed with a clear and effective integration between NSN and DSN assets, which allows seamless support for cislunar assets across both networks. This will serve both as a key test of the “One Network” approach, and also a key deadline for the full and effective integration of SCaN’s networks.

5. Becoming One Network: International Collaborations

SCaN’s work to integrate its own networks is only one part of the “One Network” approach the program is taking to close anticipated capability gaps. Another is a renewed effort to collaborate more closely with international partners. Part of that involves close work with government agencies with space communications infrastructure and overcoming the information security issues to make them active parts of SCaN networks. In parallel, one of NASA’s important strategic goals is to help build commercial and international partners to create a robust space industrial base.

While SCaN has initiated several recent efforts to amplify network partnerships, there are several key collaborations we are exploring that would tie in infrastructure to support space communications beyond GEO. One effort of note involves building on a legacy of partnership with CSIRO for the Deep Space Network to fold another Australian asset into SCaN’s “One Network” model. The Parkes Observatory, located in New South Wales, is a 64-meter radio astronomy observatory that has been operational since 1961. It is operated by CSIRO as part of the Australia Telescope National Facility.

Though Parkes is primarily used for astronomy, it has intermittently supported several crewed and robotic NASA missions. It received the live television feed of the Apollo 11 Moon landing over S-band and played a critical role a part of a series of arrayed antennas supporting the Galileo space probes Jupiter mission in the 1990's. It also was activated to support Voyager 2's transit of the heliopause in 2018. However, it has not been used actively by NASA or other space agencies in recent years. Furthermore, it has never been formally networked with DSN in the model of domestic partners like Morehead State in Kentucky, whose 21-meter antenna can work directly with SCaN as an affiliated node. SCaN is in active conversation about the possibility of again involving Parkes to support NASA space missions.

A parallel and related effort is being made in relation to the Effelsberg Observatory, located in Germany and operated by the Max Planck Institute for Radio Astronomy. Effelsberg is one of the largest fully steerable radio telescopes in the world, with a diameter of 100 meters. The observatory has intermittently supported spacecraft missions, including Voyager and Cassini. SCaN is in conversations regarding the renewed use of Effelsberg as a complement to the DSN to support deep space missions like Voyager and New Horizons on an intermittent contingency basis.

Looking forward to communication technologies beyond RF, an area where NASA has been working with international partners is in supporting the development of low-cost optical ground terminals. This has been a specific and recent focus with the Australian National University (ANU). As part of this effort, NASA views Artemis II and O2O as a significant opportunity to demonstrate new capabilities and lay the foundation for deeper collaboration. There is a technical goal to mature the ANU Quantum Optical Ground Station design and demonstrate its capability to serve as a potential ground station. As part of that possibility, NASA recently worked through export control approvals to provide the ANU team the O2O space-to-ground interface control document (ICD).

More broadly, NASA signed an agreement in 2022 with ANU and aims to expand our partnership in manners beneficial to both parties. An in-progress amendment to our current collaboration agreement would facilitate the use of NASA personnel, facilities, and test equipment in our collaboration to transfer the optical modem technology to ANU. The amendment is currently in the NASA signature cycle, and we are eager to see it fully executed. We also recognize that ANU partnering with the Australian Space Agency (ASA) to broaden Australian commercial capabilities in optical communication technology and are excited for how that aligns with NASA's mission.

These are just first steps. As SCaN looks to move towards optical networks, terminals outside the Continental United States (OCONUS) will be key to account for weather and other challenges to having effective ground terminal coverage. The program looks forward to exploring and identifying appropriate opportunities for the use of optical ground stations located abroad in nations including Australia, as we move towards fulfilling SCaN's "One Network" vision.

6. Becoming One Network: The Commercial Space Ecosystem

Unlike any other time in its history, the Agency is surrounded by a burgeoning commercial space marketplace, technological advancement, and other government agencies that share common interests in space resiliency, robustness, and performance. NASA remains a leader in space, but the global space economy outside the Agency has experienced remarkable growth in recent years—all while US government civil space investment has remained largely flat. As of 2023, estimates suggested that the space economy was worth $570 billion, representing a doubling over the past decade, and aligning with frequent mentions of space as a "Trillion dollar" domain [3]. The industry continues to expand, creating new and emerging markets that are transforming approaches to space.

The growing space economy has spurred a parallel transformation and emerging market for commercial space communication services. Future mission concepts will rely on both government and commercial capabilities, both Near Space Network capacity and Deep Space Network capacity. Integrating these diverse support services together from a technical, programmatic and implementation standpoint will be key to meet the growing needs of the future and embody the "One Network" future of SCaN.

It is hard to overstate the importance of this shift. Historically, NASA and other space agencies developed and operated their own communication systems. Yet, in domains like for near-earth DTE services, the Agency has been enacting a steady shift in this paradigm for over two decades. Now, the NSN has a proven track record of successfully integrating commercial DTE stations into its network, and indeed, over 60% of the Agency's downlinked data comes through these partners. The goal is to eventually make that number 100%. This integration is crucial as it enhances the network's reliability and expands its operational capabilities.

Furthermore, these commercial DTE providers got their start serving government missions, but they now possess the expertise to reliably support low Earth orbit missions without government interfaces. This is a success story that the Agency seeks to replicate at SCaN and beyond, in keeping with National Space Policy to leverage and facilitate a commercial space ecosystem [4]. Even when government users serve as an anchor tenant, the goal for sustainability must be to create a business model where we are one of many customers.

Even as these commercial ground stations have been integrated with the NSN, the increasing demand is poised to strain the network. This has prompted the need for more efficient transport and delivery systems, achieved through the integration of cloud infrastructure and services. SCaN's Data Acquisition Processor and Handling Network Environment (DAPHNE) is a pioneering solution to this issue that has been integrated into the ground network to handle the high-rate Ka-band downlink on missions. It plays a crucial role in managing the vast amounts of data generated by the PACE mission and DAPHNE will also underpin the even higher throughput from NISAR, and effectively working across NSN stations from various providers as "One Network." SCaN will continue developing robust solutions for the data needs of new missions, such as the SCaN Program Operations Cloud (SPOC), enhancing their operational efficiency and sustainability [5].

In parallel with these new approach to DTE support for the NSN, SCaN has been tracking how over a dozen entities have emerged that anticipate being able to provider in-space relay services, including SpaceX and Inmarsat, using technologies ranging from RF to optical. In total, these parallel non-government networks represent an incredible amount of additional capacity which is currently largely inaccessible to NASA and other government users. Recognizing these providers as part of the solution to challenges the Agency faces, SCaN has begun pivoting toward commercial services and collaborating with partners to close capacity and capability gaps as part of a "One Network" approach.

NASA's efforts are unfolding to provide commercial space relay for missions is being executed through the Communications Services Project (CSP). CSP has entered into Funded Space Act Agreements (FSAA) worth $278.5 million with six commercial satellite communication (SATCOM) companies to develop and demonstrate space-based relay services for NASA missions in low Earth orbit (LEO). These companies are cumulatively investing $1.5 billion of their own resources into this effort. After the demonstration phase SCaN will execute an open service solicitation to validate and certify SATCOM services to integrate them into the NSN service catalog.

Ultimately, this new paradigm will commercialize all NASA's space relay needs and is expected to provide lower cost and better performance for NASA missions in space. Overall, it is part of a broader necessary shift away from government owned and operated space relay service that will position the Agency for a more effective higher-throughput network future. At the same time, by validating and supporting these services for missions as part of the NSN service catalogue, SCaN's central role in supporting missions at NASA will be maintained, even as the number of providers participating as "One Network" continues to grow. NASA is already taking steps to extend this paradigm into cislunar space with a lunar relay as a surface approach, as well as an open minded exploration of possible approaches to surface wireless and other communication challenges at the Moon.

7. One Team, One Mission, One Network

SCaN faces a set of challenges unlike any in its history. Network demand is spiking in parallel with emerging technologies, new instruments, and communications complexity. A new generation of high demand missions like JWST and PACE are already creating novel capacity strains. In parallel, SCaN's network infrastructure—much of the technology from prior decades—is facing serious sustainment challenges and is in several cases starting to show its age.

The program is already pivoting to meet this moment. Ongoing efforts across SCaN are resetting the organization to embrace the Our One Team, One Mission, One Network approach. SCaN's network operations are reorienting to integrate both SCaN network and external assets more effectively in a way that ensures a coherent experience for our customers. International partners, commercial providers, and a reworked internal approach at SCaN all have a critical role to play in positioning SCaN for the future. Even as the ways these will be integrated are yet to be fully determined, the vision is clear: SCaN is reshaping itself to be a recognized customer-centric, service-oriented, high-performance leader in the space communications community.

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