SPACE COMMUNICATIONS AND NAVIGATION PROGRAM

Space Communications and Navigation (SCaN) Integrated Network Architecture Definition Document (ADD) Volume 1: Executive Summary

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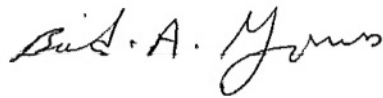
National Aeronautics and
Space Administration

NASA Headquarters
Washington, D.C.

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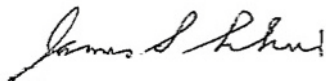_(signature)_   Jan. 28, 10

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Contents

List of Figures

List of Tables

SCaN-ADD-V1
Revision 1

Space Communications and Navigation (SCaN) Integrated Network Architecture Definition Document (ADD) Volume 1: Executive Summary

1. Introduction

1.1   General

The National Aeronautics and Space Administration (NASA) Space Communications and Navigation (SCaN) Program is responsible for providing communications and navigation services to space flight missions located throughout the solar system. The SCaN Program provides user missions with services that may include transmitting data to and from space vehicles and deriving information from transmitted signals for tracking, position determination, and timing.

This document, i.e., Volume 1 of the SCaN Integrated Network Architecture Definition Document (ADD), provides a high-level summary description of the new NASA SCaN integrated network architecture. The SCaN Program's challenges are to support the known NASA and approved U.S. and international partner mission set, and to develop and deploy new mission-enhancing capabilities (such as optical communications, antenna arrays) and make improvements in functionality using an integrated service architecture and space internetworking. This document provides an executive overview of the driving requirements and the technical architecture. It also explains how the architecture responds to challenging mission and programmatic requirements and the call for new, enhanced communications capabilities.

1.2   Background

In the summer of 2006, the NASA Administrator assigned management and Systems Engineering and Integration (SE&I) responsibilities for the Agency's space communications and tracking assets to the SCaN Office in the Space Operations Mission Directorate. The SCaN mandate centralized the management of NASA's space communications and navigation networks: the Near Earth Network (NEN), the Space Network (SN), and the Deep Space Network (DSN). The mandate also included SCaN management of the NASA Integrated Services Network (NISN), but this responsibility was later reassigned to the Office of the Chief Information Officer (OCIO). The SCaN Program was also delegated the Agency responsibility to protect necessary electromagnetic spectrum, evolve efficient and interoperable telecommunications standards, and establish a telecommunications technology program.

Since that reorganization other policy documents have provided further guidance to SCaN Program management. The SCAN Program Commitment Agreement (PCA) requires that

SCaN evolve "services in a manner consistent with a space architecture framework and mission requirements and pursue cooperation, collaboration, and cross-support with industry and other Government agencies, including international space agencies."

The PCA assigns the SCaN Program responsibility for providing communications and navigation services (including systems engineering and planning) to user missions, and maintaining and evolving the SCaN architecture to effectively and efficiently meet user missions' present and future needs.

The PCA directs the SCaN Program to create a single NASA-wide space communications and navigation architecture that:

    a. Controls the physical configuration and evolution of NASA's space communications and navigation infrastructure

    b. Defines the evolving set of standard services that the infrastructure provides to user missions, i.e., flight programs and projects

    c. Specifies the minimum set of standards that will be used by user missions to interface with these services, both in space and on the ground

The PCA also directs the SCaN Program to review NASA goals, initiatives, and missions to identify future communication needs, and to establish and manage a set of projects that accomplish SCaN Program objectives within allocated resource and schedule constraints with priority on safety, mission success, and risk management. In recognition of the limitations of the present network architecture, the SCaN Program is directed to integrate its individual networks into a unified network which will function as a single entity to provide services to user missions.

1.3 Driving Requirements

The Strategic Management Council (SMC) reviewed and endorsed the following set of SCaN driving requirements which are consistent with NASA Policy Directive (NPD) 8074.1, Management and Utilization of NASA's Space Communication and Navigation Infrastructure:

    a. SCaN shall develop a unified space communications and navigation network infrastructure capable of meeting both robotic and human exploration mission needs

    b. SCaN shall implement a networked communication and navigation infrastructure across space

    c. SCaN's infrastructure shall provide the highest data rates feasible for both robotic and human exploration missions

    d. SCaN shall assure data communication protocols for Space Exploration missions are internationally interoperable

    e. SCaN shall provide the end space communication and navigation infrastructure for Lunar and Mars surfaces

    f. SCaN shall provide communication and navigation services to enable Lunar and Mars human missions

g. SCaN shall continue to meet its commitments to provide space communications and navigation services to existing and planned missions

SCaN's Level 1 programmatic requirements are contained in the SCaN PCA and the SCaN Program Plan. As part of the SCaN system engineering process, SCaN has defined a set of program Level 2 requirements in the SCaN System Requirements Document (SCaN SRD). Other programmatic requirements from the NASA directorates are defined in jointly controlled Interface Requirement Documents (IRD) and reflected in the Level 2 SRD.

1.4   Purpose

The SCaN integrated network architecture is intentionally capability-driven, and will evolve as NASA makes key decisions involving technological feasibility, mission communication needs, and funding. The purpose of this SCaN Integrated Network ADD Volume 1 is to describe the architecture at a level of detail appropriate for program management in SCaN and the NASA Directorates. The more detailed architecture description suitable for implementing the integrated network is described in the ADD Volume 2. This document illustrates the progression of the current architecture toward achievement of the target architecture, and describes the evolving services and capabilities to be provided by the Agency's present SCaN networks (the SN, NEN and DSN) and the planned transformation from the current configuration of loosely coupled networks into an integrated network. The Volume 1 and 2 ADDs are developed in parallel with the SCaN Concept of Operations (ConOps) and the SCaN SRD. The SCaN Document Tree illustrates the relationship among the SCaN documents.

1.5   Scope

This document summarizes the evolution of the integrated network architecture for NASA's communication and navigation infrastructure for the time period 2009-2025. This plan is strategic in nature and defines three phases that roughly correspond to the following time periods:

a. A near-term phase from the present to the end of the current budget period (2009-2015), when mission plans are well understood. This phase extends up to the launch of the initial Constellation Program (CxP) Orion International Space Station (ISS) missions and the launch of challenging science missions such as the James Webb Space Telescope (JWST) and Mars Science Laboratory (MSL).

b. A second phase where somewhat reliable mission plans exist (2015-2018). This phase encompasses increasingly complex lunar science missions, and a new generation of outer planet missions.

c. A third phase that is driven by anticipated requirements and capabilities (2018-2025). This phase includes human lunar exploration, robotic Mars exploration, Mars sample return, and deployment of large format, multi-spectral imaging and Synthetic Aperture Radar (SAR) instruments at other planets.

Full integration of the individual SCaN networks into the SCaN integrated network will not be realized until the start of Phase 3; for simplicity, this document makes reference to the

integrated network for Phases 1 and 2 as well, with the implication that the individual networks are evolving into the integrated network.

The architecture is driven by the mandate to develop space communications and navigation capabilities that will enable future user missions, and also by the aggregated requirements of NASA, U.S. and international partner missions. Mission needs are documented in the Space Communication Mission Model (SCMM), which is managed by SCaN, and reflects the NASA Agency Mission Planning Manifest (AMPM) managed by NASA's Program Analysis and Evaluation Office (PA&E). Planned capabilities meet or exceed all current and planned mission requirements. One of the cornerstones of the architecture is to define an approach that remains viable in the face of programmatic and funding volatility.

A series of trade studies and Architecture Decision Points (ADPs) have been identified that will refine the evolution path of the SCaN integrated network. Section 3 contains a summary of the ADPs in each time phase. The SCaN Program will perform technology development activities and task or perform the trade studies to resolve technical issues in advance of programmatic decisions.

The scope of this ADD is limited to NASA's SCaN networks and does not encompass the architectures of external organizations, nor of supported user missions. For example, NISN, which is now operated by the OCIO, is treated as the terrestrial network and circuit provider, and is opaque to the SCaN architecture at the level described in this document. The SCaN architecture supports user mission navigation by providing tracking, radiometric, and timing services, but the SCaN Program does not directly perform user mission navigation. Aside from user mission interfaces, the architecture described in this document does not include details regarding user mission space or ground system elements.

The scope of this document does not include descriptions of programmatic processes such as review and approval of requirements, architecture, and documents, nor does it describe the implementation of such processes. These processes are all addressed separately in the SCaN System Engineering Management Plan (SCaN-SEMP) and the SCaN Program Plan (SCaN-PP).

For purposes of this document, dates associated with elements that are funded and have program-planned dates, are externally imposed milestones, or are user mission commitments are treated as "firm" dates and are underscored in the text. All other dates are notional (indicated by *italics* in the text*)* and represent the best estimated dates for planning purposes.

1.6   Document Overview

Volume 1 of the SCaN Integrated Network ADD is organized into the following sections:

a. Section 1 – Introduction describing the purpose and scope of the document, the driving requirements, and goals

b. Section 2 – Overview of the integrated network architecture, services, the concept of operations, and new capabilities

c. Section 3 – Roadmap of the integrated network and description of how the architecture will be developed phase by phase, including key architecture decision points

4

d. Section 4 – Summary

1.7   Architectural Goals and Challenges

In response to the requirements and drivers identified in guiding documents and by the SMC, SCaN management has identified a set of architectural goals and challenges that are programmatic in nature. In particular, the NASA Administrator has instructed the SCaN Program to go beyond responding to documented customer requirements, and to take the lead in developing strategic, mission-enabling capabilities in advance of identified mission requirements.

The goal of this document is to provide a high level overview of the SCaN integrated network architecture, its assets, architectural options, views, and evolution until 2025 in response to NASA's key driving requirements and missions. The architecture is a framework for SCaN system evolution and will guide the development of Level 2 requirements and designs.

The SCaN architecture must respond to a number of challenges, including:

a. Forming a fully integrated network from three pre-existing individual networks

b. Resource constraints

c. Addressing requirement-driven, capability-driven, and technology-driven approaches simultaneously

d. Interoperability among compliant NASA, U.S., and foreign spacecraft and networks and commercial systems

e. Uncertainty in timing and nature of future user mission communications requirements

f. Requirements for support of user missions already in operation, as well as those to which support commitments have already been made

g. Changes in high level requirements and direction

2. Integrated Network Architecture Overview

The integrated network architecture defines what must be done at the Program level to realize the concept of a "single, unified space communications and navigation architecture," as described by the Associate Administrator in a September 2007 memo[1] providing guidance on SCaN Program roles and responsibilities. Central to this architecture is a baseline set of core services, as shown in Figure 2-1, that are provided by all of NASA's network assets to user missions. These services are standardized and provided by common interfaces across the SCaN network.

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[1] Guidance on the New Roles and Responsibilities of the Space Communications and Navigation Office, Associate Administrator Chris Scolese, 24 August 2007.
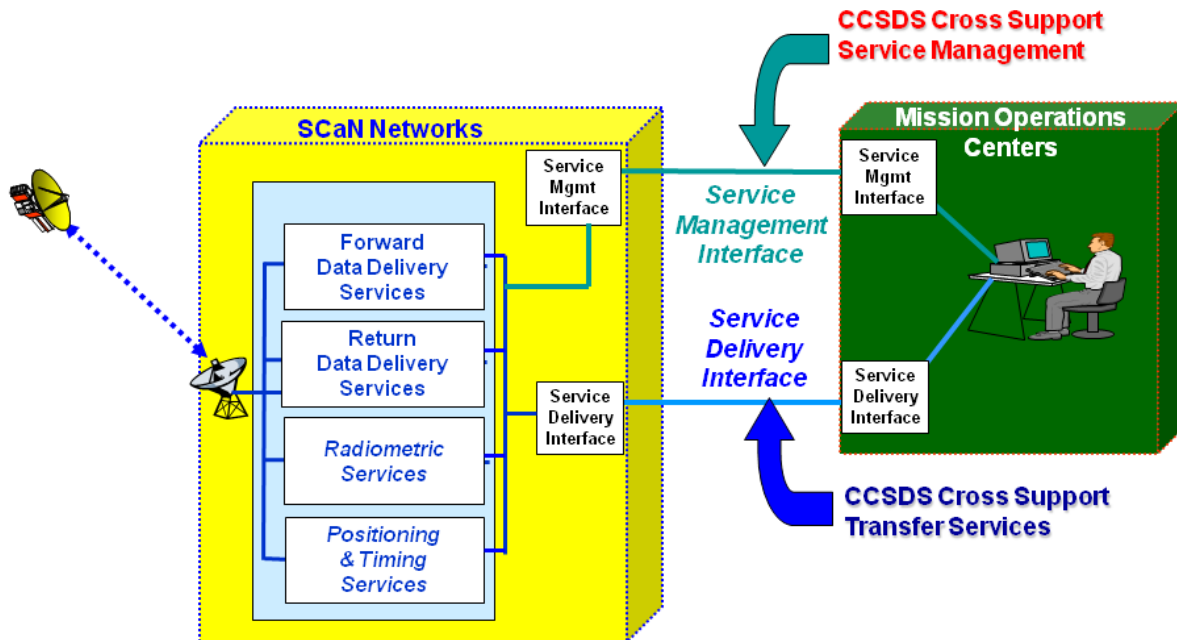
Figure 2-1. Standard Core Tracking, Telemetry, & Command (TT&C) Services

The services shown in Figure 2-1 are interoperable with those provided by networks of other organizations, both national and international, and are preferentially based upon internationally agreed standards developed within the Consultative Committee for Space Data Systems (CCSDS).

From a physical perspective, the SCaN Program has engineered an integrated network architecture that will be responsive to both future user mission requirements and availability of advanced technology. This architecture features:

a. Aggressive, yet systematic, infusion of optical communications to complement the Radio Frequency (RF) baseline (i.e., as early as Phase 2 for near Earth and Phase 3 for deep space)

b. Migration toward high-frequency RF links (e.g., Ka-band during Phases 1-3)

c. Adoption of standard services and integrated network management by the end of Phase 1 and full integration of the networks by the end of Phase 2

d. Development of a Lunar Relay (LR) capability for Exploration architecture in Phase 3 and enhancement of the Mars Relay (MR) capability

e. Augmentation and replacement of existing aging infrastructure (e.g., the ground segment at the White Sands complex during Phase 1, and 70-m antennas by Phase 3)

f. Growth into new performance realms (e.g., increased performance in data rates to meet projected demand and provide enabling capabilities during Phases 1-3)

SCaN-ADD-V1
Revision 1

g. Application of other communications technologies (e.g., Software Defined Radio [SDR], Disruption Tolerant Networking [DTN], standard communications, and physical security measures) during Phases 1-3

The following sections contain a summary of the current SCaN networks, followed by an analysis of the flow of user mission drivers and requirements down to the future architecture capabilities, and a description of the notional future architecture, including its services, operational concepts, and future capabilities.

2.1   SCaN Current Networks

NASA currently operates a complex space and ground infrastructure that supports the Agency's own space missions, as well as missions operated by partner agencies (both national and international) and by the private sector.   The current NASA space communications architecture, shown in Figure 2-2, embraces three operational networks that collectively and effectively provide communications services to supported user missions using space-based and ground-based assets:

a. **SN** – constellation of geosynchronous relays (Tracking and Data Relay Satellites [TDRS]) and associated ground systems

b. **DSN** – large aperture ground stations spaced around the world providing continuous coverage of satellites from Geosynchronous Earth Orbit (GEO) to the edge of our solar system

c. **NEN** – NASA, commercial, and partner ground stations and integration systems providing space communications and tracking services to lunar, orbital and suborbital missions

These networks are each optimized to support user missions in specific operational domains where the communications and tracking requirements are quite distinct. The NASA space communications infrastructure as a whole offers a very extensive repertoire of services, including launch/tracking range support, early orbit tracking, routine Tracking, Telemetry, and Command (TT&C), high rate science return, and emergency services. Customers include robotic and human missions at locations ranging from near Earth to deep space. The present architecture is very capable, but is also complex because of the heterogeneous nature of the network assets and the lack of consistent service offerings, interfaces, and interoperability.

The present NASA space communication networks, i.e., SN, NEN, and DSN, have been evolving independently for as long as four decades on their own respective paths, providing TT&C services to user missions. The resulting levels of integration and interoperability are less than optimum. User missions that only need services from one network are well served, but user missions that need services from more than one network face inevitable operational and testing complexities, and in some cases even need different equipment to communicate using the existing assets and services. This situation will be burdensome, inefficient, and not cost effective for new user missions such as Constellation that will need services from all three networks.
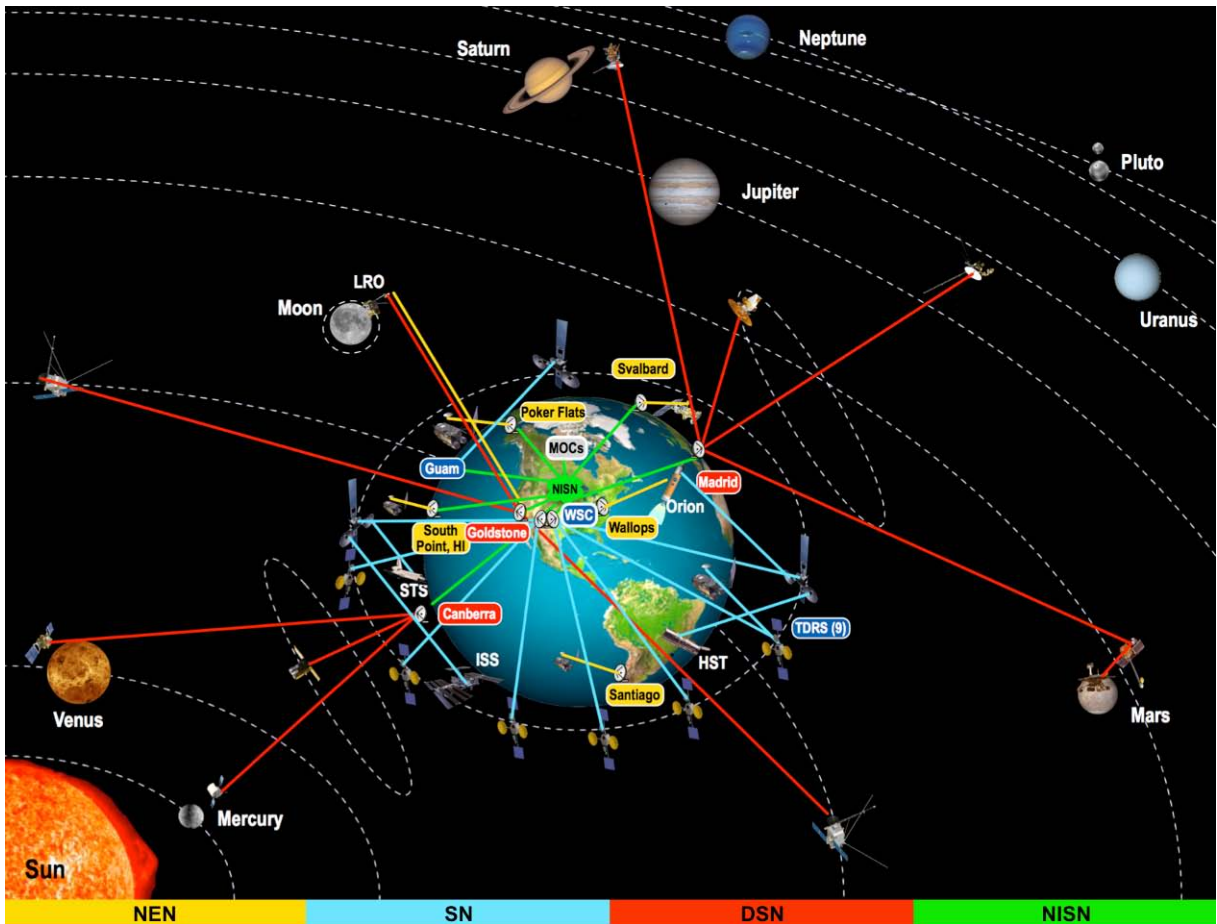
Figure 2-2. Overview of Present SCaN Architecture

2.2   Drivers/Requirements Flow down to Capabilities

Figure 2-3 shows the SCaN Level 0 requirements aligned with the time periods in which they need to be addressed. The figure also shows the most significant NASA mission drivers. Significant analysis was performed to identify the supporting capabilities needed to address these requirements and mission drivers. Figure 2-3 illustrates how the requirements and drivers flow down to the supporting capabilities listed at the bottom of the figure for each time period.

The current architecture has served NASA well, but is not optimum to provide tomorrow's science and exploration mission support.   The proposed plan includes an integrated architecture with integrated network management and standard service interfaces. It also includes new technologies such as microwave arraying, optical communications, and new navigation capabilities, and provides space networking (Internet Protocol [IP] and DTN protocols in space), which will enable new mission concepts. Collectively these elements will provide NASA missions with seamless use of the SCaN integrated network, cooperating national and international networks, and compatible space assets. These new capabilities are necessary to efficiently execute future science and exploration missions.

8

	Today	2015	2018	2025+

Level 0 Requirements

Provide space communications and navigation services to existing and planned missions.

Develop a unified space communications and navigation network infrastructure

Implement internationally interoperable communication protocols

Provide the highest data rates technically and financially feasible

Implement a networked communication and navigation infrastructure across space

Provide anytime/anywhere communication and navigation services for Lunar and Mars human missions

Mission Drivers

| Today	2015	2018	2025+
• Shuttle/ISS	• Orion/ISS	• Multiple Cooperating Robotic Missions	• Hyper spectral imaging at Mars and beyond
• Mars Landers	• Mars – Coordinated and Complex Science Missions	• Outer Planet – 1	• Human Lunar Missions
• Great Observatories	• Lunar Robotic Missions		• Earth Sensor Web
• Coordinated Earth Observation	• High Data Volume Hyper Spectral Missions		• Mars Exploration
• LRO	• SAR Earth Observation		• Mars Sample Return

Capabilities

Today	2015	2018	2025+
• Up to 300 Mbps (SN)	• Up to 1.2 Gbps (SN/NEN)	• Integrated Network Management	• Up to 1.2 Gbps from the moon (optical)
• Up to 150 Mbps (NEN)	• Standard TT&C Services	• Integrated Service Execution	• Optical Communications to 100 Mbps (planetary)
• Up to 6 Mbps at 1 AU	• Up to 150 Mbps (DSN) – 1 AU	• Space Internetworking	• Lunar far side coverage
• Radiometric Services	• Radiometric Enhancements		• High capacity multi-node
			• Inter-networking interoperability

Figure 2-3. Requirements & Mission Phasing, Capabilities Flow

2.3   SCaN Future Architecture

The vision for the future SCaN architecture is to build and maintain a scalable and integrated infrastructure that provides comprehensive, robust, and cost effective space communications services at order-of-magnitude higher data rates to enable NASA's science and exploration missions.   This infrastructure can readily evolve to accommodate new and changing technologies and will preserve current capabilities to support user mission critical events and emergencies.

In the SCaN future architecture, as illustrated in Figure 2-4, the current SCaN networks will function as a single integrated network by implementing an architecture that includes a consistent suite of international standards, interfaces and processes. While the different operating domains and unique customer needs will require some distinct capabilities, the integrated network will use common crosscutting standards and implementations to the greatest extent possible.   An integrated network management function will serve as the interface for all NASA SCaN network customers.   In addition to existing physical, information technology, and communications methods, NASA will adopt new standardized

9

security measures for managing access control and ensuring confidentiality, system integrity, and availability.
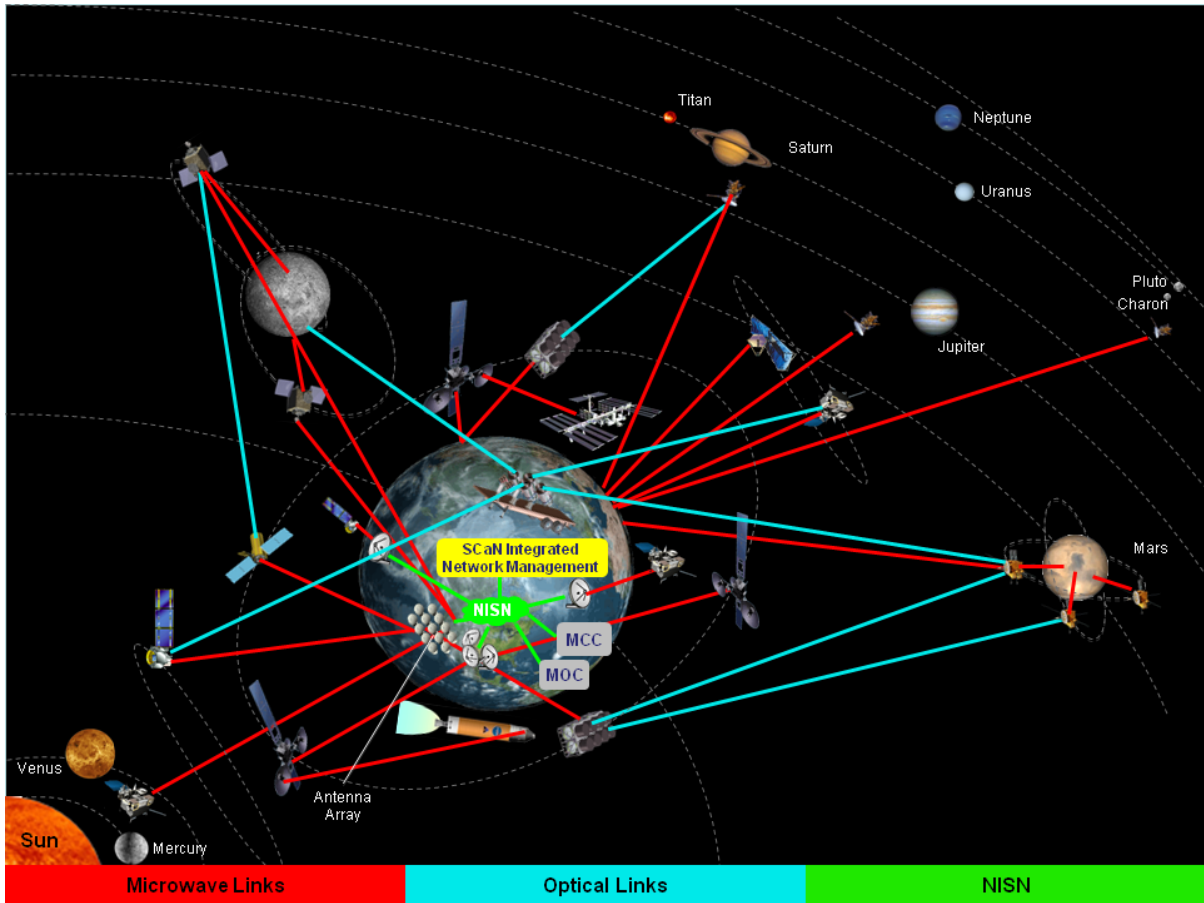
Figure 2-4. SCaN Notional Integrated Network Architecture (circa 2025)

The SCaN future architecture has the following features:

a. Solar system-wide coverage

b. Anytime, anywhere connectivity for Earth, Moon, and Mars

c. Integrated service-based architecture and network management

d. Leveraged new technology (optical, arraying, SDR)

e. International and commercial interoperability using standard interfaces

The future architecture includes a baseline of highly reliable low to high rate microwave links, and augments them with very high rate optical links to provide direct-to-Earth and relayed communications for user missions. The following sections describe the new capabilities that deliver these services, along with the corresponding mission drivers, specific infrastructure enhancements, and performance benefits.

The SCaN Program has adopted and/or adapted internationally standardized protocols and interfaces to ensure interoperability among the SCaN assets, and with space and ground

assets of NASA, U.S., and international partners and commercial providers. NASA has preferentially selected CCSDS space communications and data exchange standards where available. In addition, other international standards (such as the IP suite and surface wireless standards such as Institute of Electrical and Electronic Engineers [IEEE] 802.xx) may be used where they are applicable. The SCaN Program works closely with the CCSDS and other international standards bodies to evaluate and adopt effective, interoperable standards as well as conduct development activities in areas where new standards are required. The end result is a standards-based infrastructure with defined compliance points for interoperability. The nominal assumption in the architecture is that any external systems—including those of other agencies and commercially provided systems—will be compliant with these internationally agreed and supported standards and interfaces.

To the extent practical and efficient, the integrated network will use integrated services and common implementations for similar functions, thereby reducing the costs of developing, operating, and sustaining unique systems. These changes will facilitate a seamless and efficient interface for SCaN customers and increase efficiency of network systems. Evolution of the SCaN network will be driven by both mission requirements and insertion of new, mission-enabling technologies. Customers will be strongly encouraged to use the available standard services whenever possible.

Through system upgrades and insertion of microwave arraying, the SCaN Program will improve the performance of NASA's RF-based assets to support 1.2 Gbps in the Earth domain, and 150 Mbps in the deep space domain[2]. Arraying will also improve the reliability and flexibility of SCaN services by providing sub-array capabilities and soft failure (failure of a single antenna in the array will not result in service loss, but will result in a slight degradation of the performance of the system). NASA will use a combination of RF and optical assets synergistically to enable future Agency missions. This portfolio of diverse capabilities will allow mission designers to efficiently realize new science and exploration mission concepts.

2.4   Integrated Network Service Architecture

The integrated network service architecture, illustrated in Figure 2-5, provides SCaN customers with the capabilities to seamlessly use any of the available SCaN assets to support their missions. It also allows the SCaN Program to optimize the application of its assets to efficiently meet the collective needs of Agency missions. The service-based architecture includes: common services; common processes for network assets and user missions; internationally interoperable, standard TT&C services; and integrated network management and data delivery elements to maximize access to all of the SCaN Program's capabilities.

The integrated network architecture shown in Figure 2-5 includes the network assets of NASA's current DSN, SN, and NEN as well as future expansions. These assets are shown grouped by mission domain. As with the current NEN, the Near Earth element of the integrated network would include both NASA-owned ground stations and contracted

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[2] Analysis has shown that this is achievable at one Astronomical Unit [AU], assuming 180W spacecraft transmitting power for Ka-band using a 3-m high-gain antenna, and three arrayed 34-m ground-based antennas.

commercial stations. The figure shows separately the assets of other agencies and of commercial vendors not under contract to the integrated network. The use of internationally interoperable, standard services enables user missions to interface seamlessly to the SCaN integrated network as well as these external entities. SCaN may interface with other agencies via the standard service management and execution interfaces. Mission Operations Centers (MOCs) may interface with SCaN or other agencies via the standard service management and execution interfaces.

Barring real world physical constraints and limitations of the communications assets, all of the standard SCaN services will be available from the SCaN integrated network. The SCaN Program will publish a standard catalog of services and ensure secure access to TT&C services via a consistent set of interfaces for planning, requesting, delivering, managing and reporting.
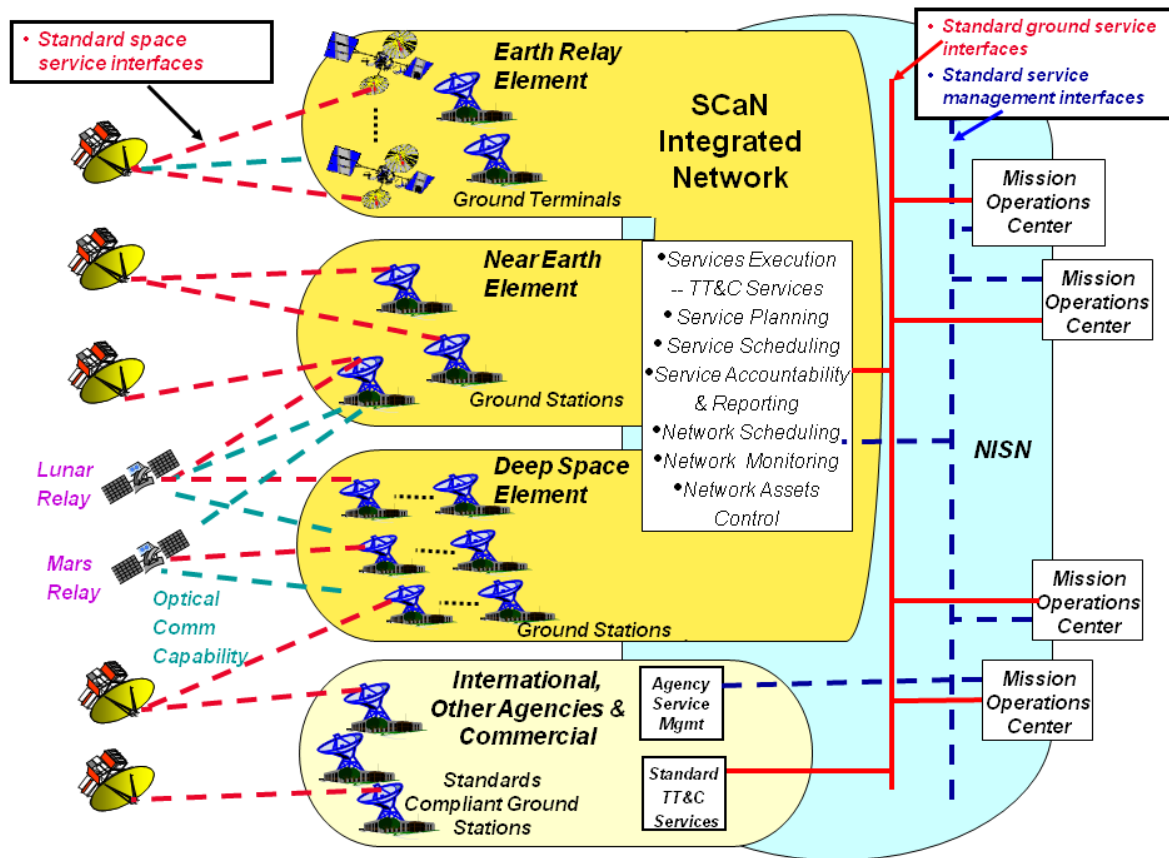
Figure 2-5. Integrated Network Service Architecture

SCaN Integrated Network services include:

    a.   Forward data delivery services

        1.   Forward Command Link Transmission Unit (CLTU) service

        2.   Forward transfer frame service

SCaN-ADD-V1
Revision 1

     3.   Forward internetworking service

     4.   Forward file service

  b.   Return data delivery services

     1.   Return all frames service

     2.   Return channel frames service

     3.   Return internetworking service

     4.   Return file service

     5.   Return unframed telemetry service

  c.   Radiometric services

     1.   Raw and Validated radiometric data

     2.   Delta-Differential One-way Ranging

  d.   Position and Timing services

     1.   Time distribution

     2.   Support for trajectory determination and prediction

  e.   Specialized Services

     1.   Unique services (e.g., radio science)

     2.   Legacy services

2.4.1   Integrated Network Management

The SCaN integrated network will provide a common set of services and interfaces across the network. Although some user missions only use one network asset, many user missions require the services of more than one asset. To reduce the customer burden, improve SCaN integration, and enable an integrated service commitment process, the SCaN Program will offer an integrated network management function (portrayed in Figure 2-6) that will provide access to all of the services provided by the SCaN integrated network, plus the compliant services offered by national, international, and commercial partners/providers. User missions would use the single common network management function, as negotiated in accordance with (NPD) 8074.1, to access the services that they require.

The integrated network management interface will maximize commonality for essential service and network management functions among the integrated network assets and future capabilities such as the Lunar and Mars Relays and optical communication. The integrated network management interface will provide user missions with a set of standard service management functions primarily implemented using CCSDS service management standards, and will offer these functions using secure interfaces. The integrated network management function will provide user missions with standard data delivery services using similarly secured interfaces.
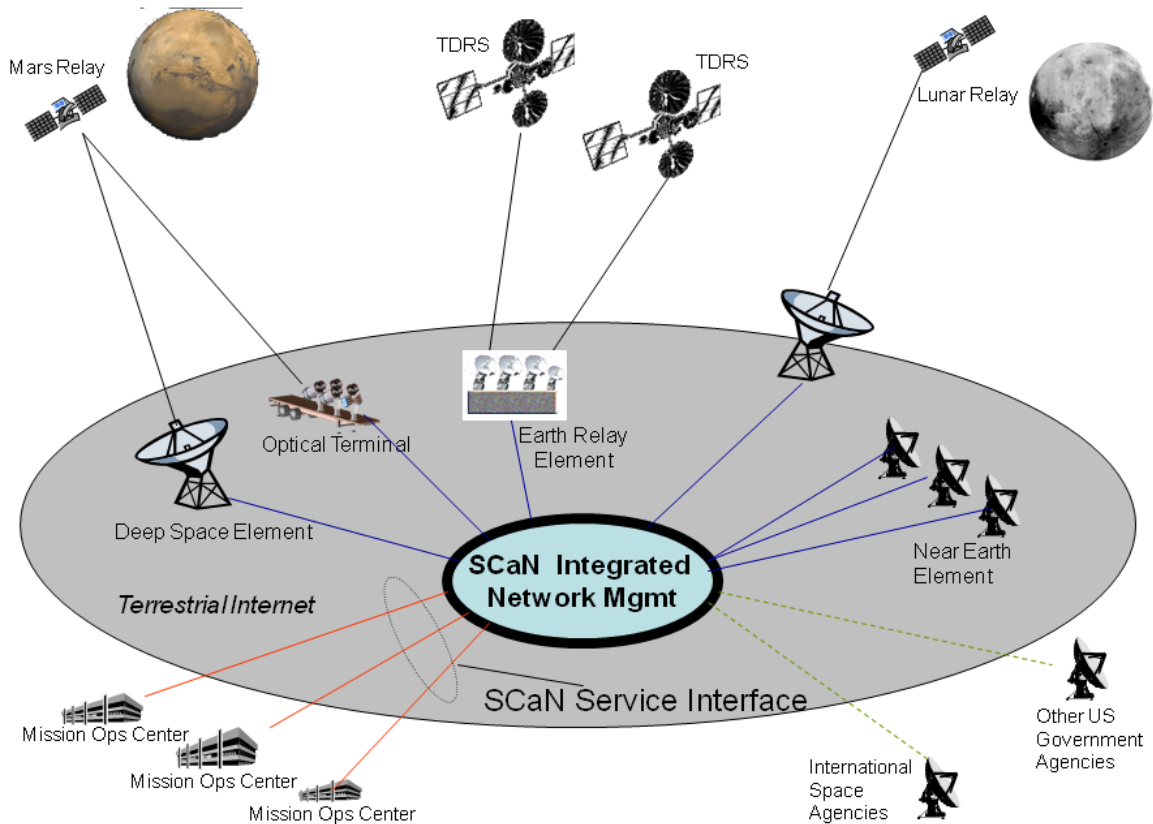
Figure 2-6. Integrated Network Management Interface

2.4.1.1 Mission/Program Drivers

In particular, Exploration Systems Mission Directorate (ESMD) missions and many near-Earth Science Mission Directorate (SMD) missions currently require the services of multiple SCaN networks. The driving requirements call for a unified network infrastructure capable of meeting user mission needs. To fulfill this requirement at best value to NASA, SCaN requires a service architecture with integrated network management across all asset domains, which is expected to maximize operations efficiency and reduce Operations & Maintenance (O&M) costs. Provision of seamless interfaces for service requests to user missions is critical to reduce the number of different interface options—both space and ground—that must be developed and operated.

2.4.1.2 Infrastructure Enhancements

Infrastructure enhancements include:

    a. Standard service management functions for the integrated network

        1. Service planning

        2. Service request scheduling

3. Service accountability reporting

b. Common network control functions for the integrated network

1. Network scheduling

2. Network asset configuration and control

3. Network asset monitoring

4. Space Internetworking management

c. SCaN Services Catalog accessible at the network management interface

2.5 Integrated Network Architecture Concept of Operations

By the end of Phase 1, the operational concept will primarily involve the establishment of a common set of service and service management interfaces between the SN, NEN, and DSN and their customers. The key feature of this concept for operations is the introduction of common internationally interoperable interfaces, protocols, and processes across the three networks and the initial implementation of integrated network management and integrated service execution. This commonality of interfaces and processes will allow the SCaN Program to assist customers through a common planning and scheduling interface, regardless of the SCaN assets that eventually serve a customer. The use of common protocols across the networks will also allow NASA to employ a common set of test equipment and procedures for customer communications system compatibility verification and validation, and employ commercial service providers that use compliant interfaces. NASA must implement these changes to achieve a SCaN integrated network architecture and set the stage for the Agency to provide high-layer routed and store-and-forward internetworking services. Additionally, this phase includes the addition of dedicated communications resources into the SCaN infrastructure such as the WS1 antenna at White Sands which provides Ka and S-band services to the Lunar Reconnaissance Orbiter (LRO).

By the end of Phase 2 all of the existing SCaN networks will be completely integrated into the final configuration of the SCaN integrated network. This network architecture will include integrated service management functions, common network control functions, and common service interfaces. It will also include adoption of common and/or centralized control and data delivery services across the network. The final form of this end state is still being refined as a result of architecture trade studies and analyses.

The introduction of LR assets, such as Lunar Relay Satellites (LRS) and space internetworking nodes, into the SCaN integrated network in Phase 3 will extend SCaN services to the lunar missions, and will be a major addition to the SCaN operational concept. The LR assets will provide interfaces to the surface elements developed by other directorates, and will provide high-rate communications and high-precision navigation services for much of the lunar vicinity including regions out of line-of-sight of Earth, filling a coverage gap. Operational details of the LR assets within the SCaN Program are still being refined, as upcoming mission architectures and requirements are defined.

Optical terminals and optical relay services will have a concept of operations similar to today's RF ground and relay systems, but will have some different operational considerations. These considerations will include restriction of operations to minimize

interference from sunlight, and more frequent mitigation of weather interruptions (due to cloud cover for Earth-based systems) through handovers, as compared to RF systems.

The concept of operations for Phase 3 builds upon the previous capabilities in various ways including: support of a possible lunar outpost, extension of optical links to Mars, addition of space-based optical array capabilities to relay signals between the Earth and Mars, transition of a Mars Relay capability from SMD to the SCaN Program, and any modifications of the MR required for SCaN to provide the standard data relays required for Mars missions.

A permanent lunar outpost will have different communications requirements than individual user missions that only require services during certain time windows. Communications link scheduling services will require alteration or expansion to accommodate the lunar surface systems.

The addition of orbiting optical relays implies that the SCaN Program will need new technology and modified and/or new operations centers. The orbiting relays, however, will eliminate the weather-induced operational challenges encountered with earlier Earth-based optical systems.

Mars-orbiting relays will require support for DTN store-and-forward networking services and on-demand network access without human scheduling or intervention.

2.6 Enhanced and New Capabilities

Enhanced and new capabilities that need to be implemented in the three phases of the architecture evolution plan are presented below. These capabilities are designed to provide new, mission-enabling functionality and to meet and exceed the requirements of the aggregate set of supported user missions. NASA missions are predominantly cited for reference; however, international partner missions may be supported, as well.

Activities to extend capability and capacity in the near Earth domain include the addition of TDRS K and L by end of Phase 1; the SN Ground Segment Sustainment (SGSS) efforts by the end of Phase 1; upgrades to support Constellation launch and ascent in Phase 1; and upgrades to support Constellation Lunar missions including migration to Ka-band starting in Phase 2. For the deep space domain, activities include the 70m replacement with antenna arrays starting in Phase 2; upgrades for Constellation Lunar missions in Phase 2; and migration to higher frequencies (such as Ka-band) starting in Phase 1 and extending through Phase 3.

2.6.1 Enhanced Near Earth Domain Capability

The near Earth domain, shown in Figure 2-7, encompasses operational assets on and near the Earth, up to lunar and Lagrange distances. The mission/program drivers for changes in this capability are described below.
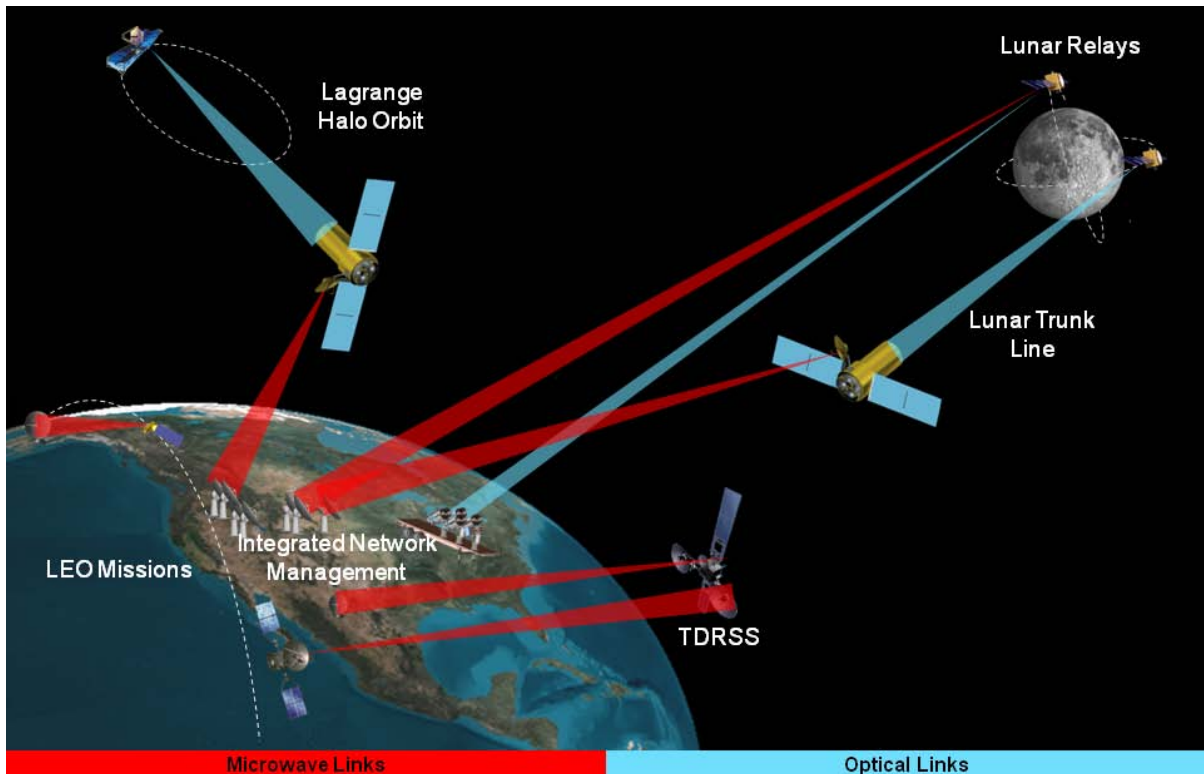
Figure 2-7. Enhanced Near Earth Domain Capabilities

2.6.1.1 Mission/Program Drivers

As indicated in Figure 2-3, Lunar robotic missions are near-term drivers that require high-rate return links. Orion ISS missions and other human lunar missions require: robust communication for human flight/safety, high rate lunar trunk lines, near continuous tracking coverage, and seamless user mission support by all of the SCaN network assets. Science spacecraft such as the JWST and the Joint Dark Energy Mission/International Dark Energy Cosmology Survey (JDEM/IDECS) require high-rate science data return at Lagrange point 2 (L2) distance. Other mission types such as large format imagers, SARs, Lagrange point and Earth-orbiting sensor webs will benefit from high data rate downlinks and space internetworking.

2.6.1.2 Infrastructure Enhancements

Infrastructure enhancements include:

    a. Optical Initial Operational Capability (IOC): flight and ground terminals

    b. Earth-orbiting optical relay for higher availability

    c. RF capacity and performance upgrade

    d. TDRSS

        1. TDRS M & N

17

2.   Multiple aperture arraying

3.   TDRSS navigation beacon (TDRSS Augmentation Services for Satellites, or TASS)

e. LRS

f. Integrated Network Management

g. Space internetworking nodes with IP and DTN

2.6.1.3   Performance

Within the near Earth domain, the near Earth optical IOC (*2018*) will provide at least 1.2 Gbps on the return link to Earth, and 100 Mbps on the forward link. RF return link enhancements will provide at least 150 Mbps at L2 using Ka-band, and at least 1.2 Gbps for Low Earth Orbit (LEO)/Middle Earth Orbit (MEO) using Ka-band. RF forward link enhancement will provide between 25 to 70 Mbps for user missions at locations from LEO through lunar distances using Ka-band.

Near Earth domain assets provide anytime, anywhere connectivity within Earth line-of-sight and global Earth coverage. Standard services will be used across the integrated network.

2.6.2   Enhanced Deep Space Domain Capability

Through system upgrades and insertion of microwave arraying, the SCaN Program will improve the performance of NASA's RF-based assets to provide robust support for Mars exploration and user missions to outer planets (see Figure 2-8). Capabilities will include higher sensitivity for future heliospheric missions, interstellar probes, and other user missions, as well as higher data rates. Optical communications will be added to augment RF for higher rate data return.
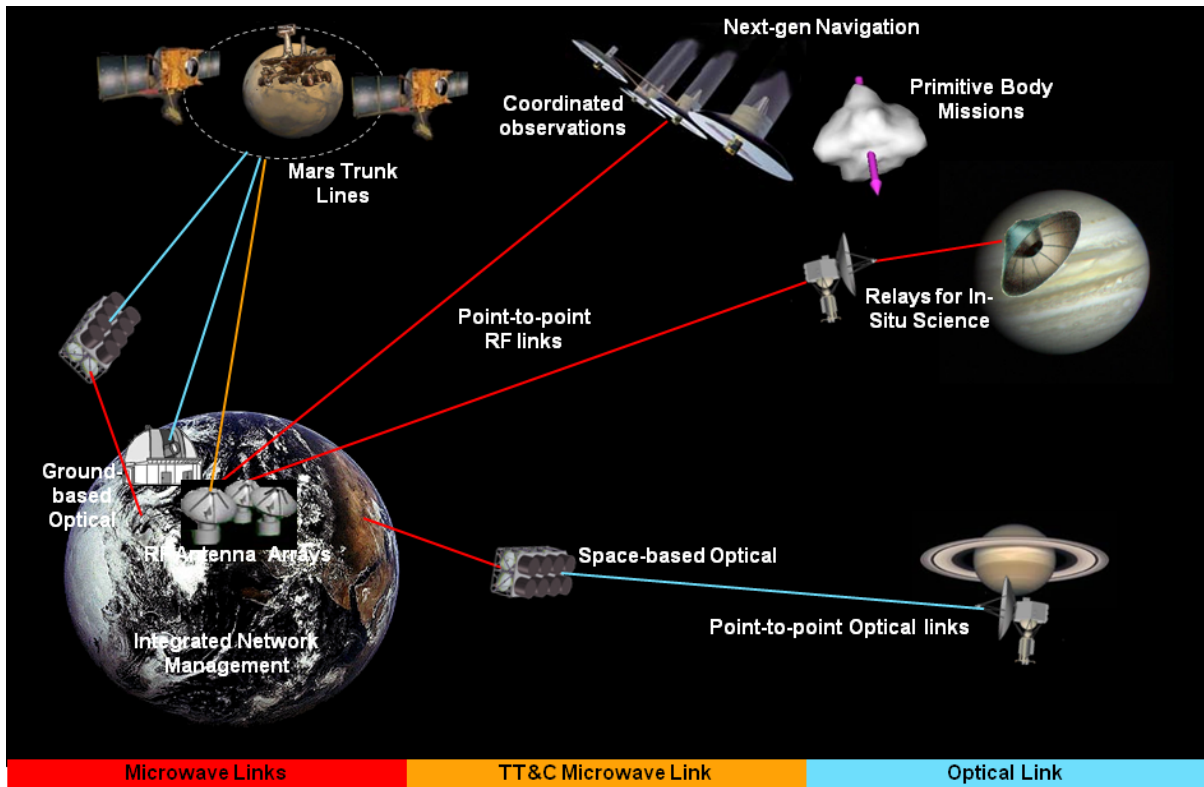
Figure 2-8. Enhanced Deep Space Domain Capabilities

2.6.2.1 Mission/Program Drivers

NASA is considering a number of new missions to Mars and the outer planets, including Mars Sample Return, which will require higher radiometric accuracy for precision rendezvous and docking; Mars Atmosphere and Volatile EvolutioN (MAVEN), which will extend reliable communications for the MR; Mars Science Orbiter, which needs the MR and high-rate trunk line; Outer Planet missions (e.g., OP-1), which require long distance links to Jovian or Saturnian spacecraft and are survival-time limited missions; and New Frontiers missions, which will need extreme distance return link and emergency TT&C.   Many of these missions, such as the Mars Exploration Joint Initiative (MEJI), will be collaborative ventures with European or other international agencies.

2.6.2.2 Infrastructure Enhancements

Infrastructure enhancements include:

    a. Optical IOC: flight and ground terminals

    b. Deep space optical relay for higher availability

    c. RF ground stations

        1. 70m replacement with antenna array

19

2.   Capacity and performance upgrade

d.   Integrated Network Management

e.   Space internetworking nodes with DTN

2.6.2.3   Performance

The deep space communication capability will continue to provide robust TT&C and emergency communication services using RF frequencies, but will emphasize the use of Ka-band for high rate data return.   A scalable array of RF antennas will provide robust emergency X-band TT&C and high-power uplink capability, and will deliver anytime, anywhere connectivity within the Earth's line-of-sight.   Arraying will also improve the reliability, sensitivity, and flexibility of SCaN services by providing sub-array capabilities and soft failure functionality.

To deliver the highest performance data return, balanced against reduced spacecraft mass and power, a new deep space optical IOC will be developed offering at least 100 Mbps return data rates at one AU that will be extensible to one Gbps, and forward rates greater than two Mbps.   Optical communications performance may be constrained, however, by weather effects, as well as sensitivity to solar energetic particle events.   Pathfinder missions will be used to mature the technology and evaluate these potential constraints.

2.6.3   Lunar Relay Capability

The introduction of LR assets into the SCaN integrated network will extend SCaN services to user missions in the lunar vicinity.   The configuration and evolution of LR assets within the SCaN architecture are based on emerging communication and navigation requirements of NASA exploration and science missions, as well as SCaN Program Level 0 Requirements. The LR portion of the SCaN architecture, shown in Figure 2-9, shows trunk links between Earth and the Moon, including elements in Low Lunar Orbit such as Constellation's Orion Crew Exploration Vehicle, and lunar orbit to surface links.   The introduction of LR assets into the SCaN architecture responds to NASA's ESMD plans to accomplish human return to the Moon no later than *2023*.   The termination point of the SCaN architecture resides at the interface from the LRS to lunar surface and orbiting elements such as habitats, rovers, and astronauts participating in extravehicular activities.
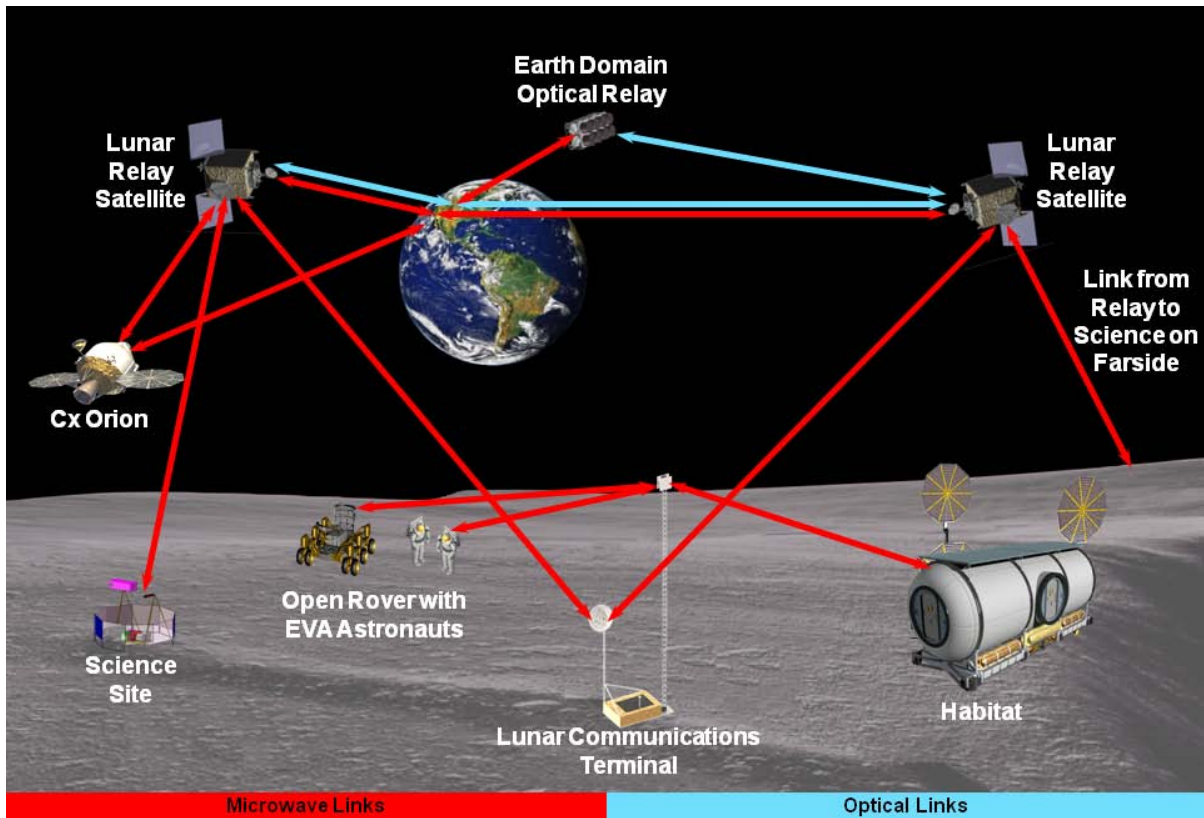
Figure 2-9. Lunar Relay Capability

2.6.3.1 Mission/Program Drivers

NASA's SMD has proposed an International Lunar Network (ILN) of robotic geophysics stations on the Moon to probe the Moon's deep interior structure and composition, starting in *2018*. Pre-formulation studies support four near-side ILN Landers (anchor nodes) in the *2018 era*. However, a small lunar relay capability may be required for international partner ILN nodes in the same timeframe. The primary drivers for high rate return for lunar exploration are the first Altair lander test in *2022*, followed by human lunar return ("Boots on the Moon") in *2023*, and the initial lunar outpost slated for completion in *2025*.

2.6.3.2 Infrastructure Enhancements

Infrastructure enhancements include:

a. Optical IOC: flight and ground terminals

b. Earth-orbiting optical relay for higher availability

c. LRS

d. Space internetworking nodes with IP and DTN

21

e.   Integrated Network Management

2.6.3.3   Performance

The LR portion of the SCaN architecture will be scalable to provide 60-100% coverage depending on customer requirements, the number of orbital assets, and selected geometry. The LR assets will provide up to 1.2 Gbps from the Moon to Earth, and 20 Mbps uplink from Earth to the Moon via optical links. The LR assets will provide at least 250 Mbps by RF links from the lunar vicinity, and will provide radiometric capabilities for precision approach and landing (with less than 100 m uncertainty) and to support surface roving.

The LR assets within the SCaN architecture will enable international and commercial collaboration and interoperability. The LR portion of the SCaN architecture will provide multiple access communications techniques and protocols to provision simultaneous communications to multiple lunar orbiting and surface elements.

2.6.4   Mars Relay Capability

The present MR, which is currently developed and operated by NASA's SMD, provides an initial communication relay capability for user missions on the surface and in the vicinity of Mars by including relay communications payloads on science orbiters. In the future it is expected that exploration vehicles and science spacecraft operating on or near the Mars surface will receive communication, navigation, and timing services via MR assets, which may be developed and operated by SCaN (to be decided at the NASA Agency level). The future MR architecture will be incorporated into the SCaN integrated network, and will use one or more dedicated relay satellites with store-and-forward, space internetworking, and system capabilities evolved from the early MR and future LR designs (see Figure 2-10). Two significant changes from current practice will be:

a.   uniform adoption of a standard file relay and internetworking communications architecture, and

b.   management and operation of the relay communications assets as essential elements of the SCaN service framework.
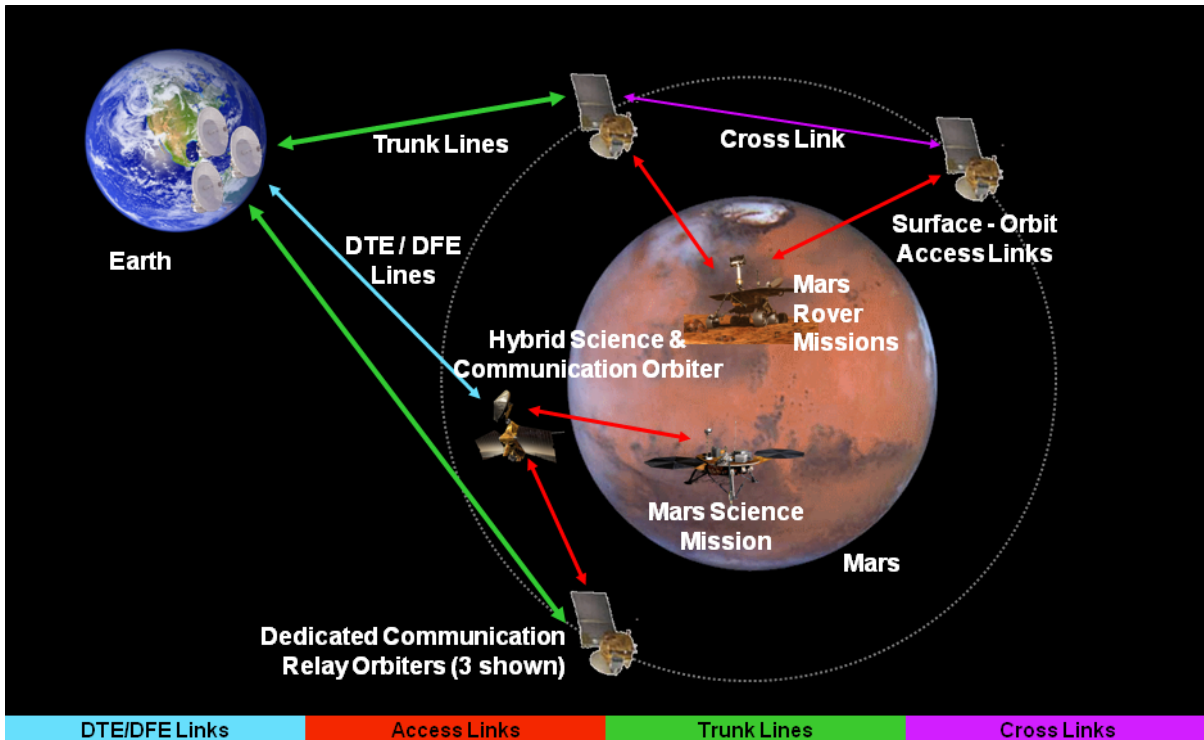
Figure 2-10. Mars Relay Capability

2.6.4.1 Mission/Program Drivers

The near-term primary drivers for the MR are the upcoming missions to Mars, which include: MSL (long distance rover), MAVEN (extends reliable communications for Mars Relay), the collaborative robotic Mars Exploration plans reflecting results of the MEJI, and other international agency partner missions. Mars Sample Return may drive higher navigation performance in Phase 3 because the mission requires higher radiometric accuracy for precision rendezvous and docking. Human exploration precursor missions are expected by the *2030* timeframe, driving requirements for dedicated Mars communication/relay orbiters.

2.6.4.2 Infrastructure Enhancements

Infrastructure enhancements include:

a. Hybrid science/communication orbiters: relay payloads on science spacecraft

    1. Telecommunications, data relay, navigation, and timing services

    2. Store-and-forward file networking and initial space internetworking

b. Dedicated communication/relay orbiters: scaled for higher availability

    1. Extended space internetworking services

c. Space internetworking nodes

d. Integrated Network Management

2.6.4.3   Performance

While the exact implementation plan and ownership of these MR assets is yet to be decided, the defined architecture is scalable and can easily evolve to support the human exploration phase and the use of higher data rate instruments like synthetic aperture radars and hyperspectral imagers. Based on easily achievable spacecraft designs, near-term return data rates of up to six Mbps RF are being delivered from Mars at one AU; up to 150 Mbps will be achievable in the long term, using more powerful transmitters and arrayed antennas. For the optical trunk lines to Earth, rates of at least 600 Mbps (Mars closest approach) can be achieved. Radiometric and new optimetric (i.e., observables derived from the optical link) capabilities will be provided to support precision approach, landing, and surface roving.

The MR and its services will be implemented in compliance with CCSDS standards and Interagency Operations Advisory Group (IOAG) space internetworking cross support recommendations to maximize interoperability between NASA-developed assets and those developed by international partner agencies. This approach will also maximize commonality in service/network management among the relay and landed assets. The use of SDRs that embed this internetworking service functionality will reduce customer burden and enable delivery of interoperable DTN and file relaying services.

2.7   Other Technology and Standards Infusion

To implement the SCaN integrated network architecture, several technologies need to achieve at least Technology Readiness Level (TRL) six, and several key standards need to be established. The SCaN Program's Technology and Standards functions are carrying out these tasks and maturing targeted technologies where needed.

Key optical technologies will be required by *2015* for the successful implementation of the optical communication link capability, including demonstration of efficient direct-to-Earth optical links utilizing photon counting receivers. Additional technologies needed by *2020* include inertial stabilization and space-based photon counting receiver technologies, which will enable the Earth-orbiting optical relay satellites. By *2025*, adaptive and lightweight optics technologies will enable the deep space optical communications IOC. SDR technologies will be needed to facilitate the LR implementation. The SCaN Program's Spectrum function will seek additional frequency allocations in the 22 and 40 GHz bands, as well as protect current SCaN frequencies in the 37-38 GHz band for use by all the network assets. DTN technologies will be needed to enable internetworking throughout the solar system and beyond.

The development of a series of international standards as well as new technologies (e.g., Navigation Beacon - TASS and multiple TDRS antenna arraying) will enable the SGSS modernization efforts by 2015. The SCaN Standards group is developing a suite of internationally approved communications standards, including IP over CCSDS, DTN, Low Density Parity Check (LDPC), and multiple access standards to enable international collaboration and interoperability in the lunar vicinity. The SCaN Program will use these

standards to further support network integration, space internetworking, and specifically support the Constellation Program's Orion launches and other lunar exploration missions.

3. Integrated Network Roadmap

The SCaN Program has created an Integrated Network Roadmap (Figure 3-1) to show how NASA will develop the integrated network and its capabilities over time. The roadmap depicts an orchestrated timeline of phased evolution toward the target SCaN integrated network architecture, identifies major ADPs, and shows the relationships among the drivers, network assets, and activities. It provides NASA with guidelines for budget planning and technical efforts. This roadmap shows all planned, potential technology maturation and infusion paths, but not all of these paths will necessarily eventuate. The intent of the ADPs is to permit evaluation and selection of options at key points to decide the final path that is to be taken. The evaluations are based on technology maturation, feasibility, mission set, costs, and other relevant technical and programmatic concerns.

The following sections contain descriptions of the SCaN integrated service architecture for each of the three time phases of deployment. The discussion includes the complete chronological set of ADPs identified for each phase. Volume 2 of the SCaN ADD contains a description, rationale, set of related decisions, and set of associated trade studies for each ADP; for brevity, only the ADP title and a short description are provided in this document. The section also contains a brief overview discussion of security considerations.

3.1   Security Elements of the Architecture

Security considerations are discussed only at a high level in the preceding sections, but they are a key part of the overall SCaN integrated architecture. Security elements addressing end-to-end confidentiality, integrity, and availability are present at many levels in the architecture, and include traditional physical and perimeter security, access control and authentication per NASA Procedural Requirement (NPR) 2810.1, data encryption and digital signatures where required, link and network layer communications security, and use of separate security domains and a layered deployment architecture to provide protection against a variety of attack vectors.

3.2   Phase 1 Evolution (2009-2015)

One of the most significant early steps in the SCaN architecture evolution plan is to provide a common set of standard services, interfaces, processes, and protocols for user missions, which will allow SCaN customers to interface seamlessly to all of the network services. The adoption of the initial integrated network management interface and standard services across the network will facilitate customer access to all assets of the SCaN architecture, enabling more efficient and effective user mission support. These services will be internationally interoperable to facilitate future international science and exploration missions.
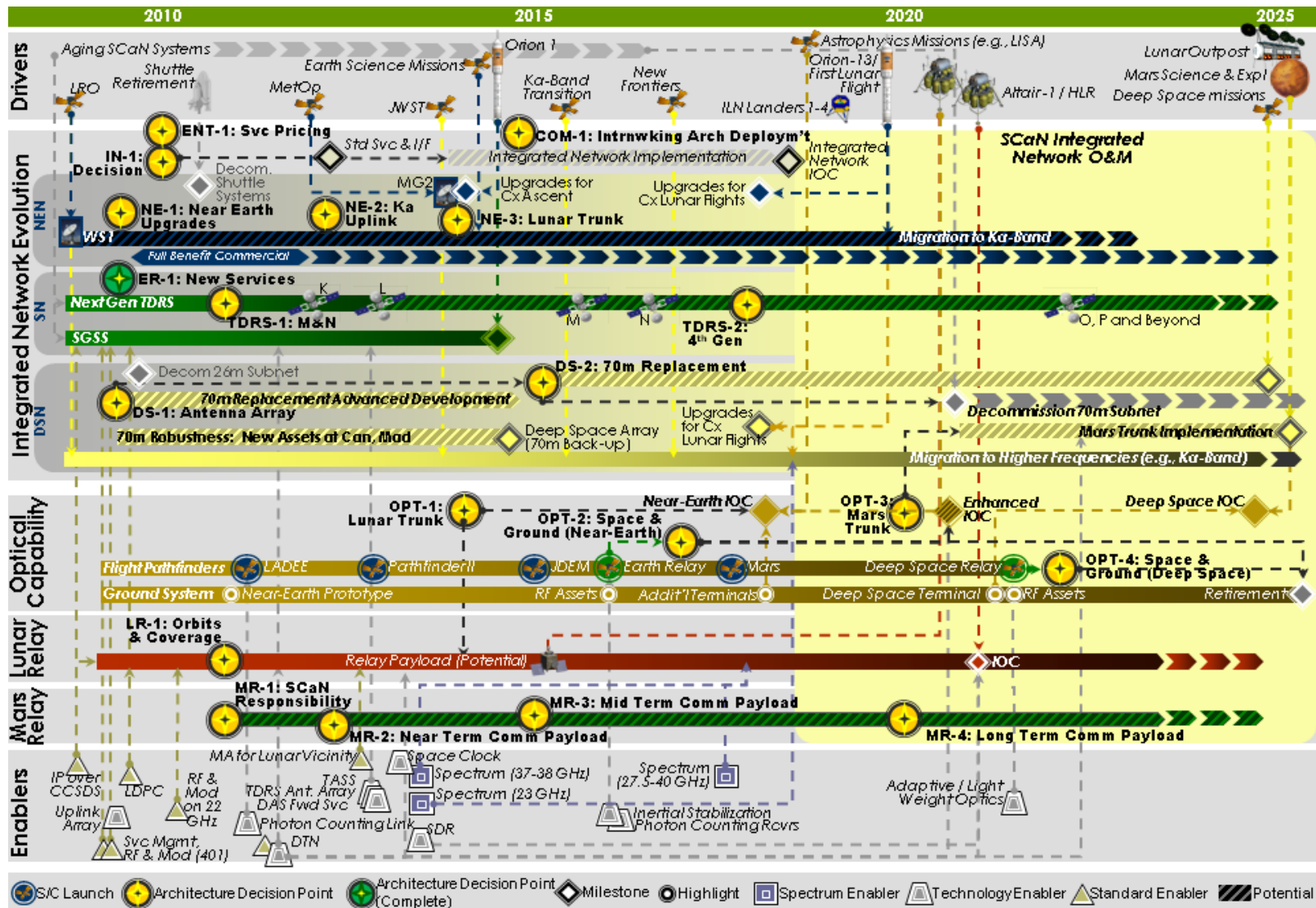
Figure 3-1. Integrated Network Roadmap by Phase

The first phase also includes significant increases in microwave data throughput, providing at least 1.2 Gbps in the near-Earth (LEO) domain and 150 Mbps (at one AU) in the deep space domain. Additionally, the SCaN Program plans several pathfinder missions to demonstrate technologies such as optical communications near the Moon, use of DTN, and SDRs. These pathfinders are designed to retire risk and allow NASA to gain operational experience before these technologies are put into operational use. Finally, this first phase involves the replenishment and modernization of aging SCaN Program systems, including targeted capacity and robustness increases to maintain highly reliable SCaN services for our Nation's space missions.

3.2.1 Phase 1 Architecture Decision Point Summary

Table 3-1 lists the Phase 1 ADPs and their associated descriptions.

Table 3-1. Phase 1 ADP Summary

Year	Phase 1 (2009-2015) Architecture Decision Point Descriptions
2009	**DS-1: Deep Space Antenna Array –** resolve the outstanding tactical and strategic issues concerning the deep space antenna array, such as optimal antenna size, spectrum bands, uplink arraying
2009 **(Complete)**	**ER-1: New Earth Relay Services –** determine which new services should be included into the Earth Relay element, and when they should be provided
2009	**NE-1: Near Earth upgrades for Constellation ascent –** define the implementation approach to meet the Constellation launch requirements including dissimilar voice and Developmental Flight Information
2010	**ENT-1: Unified Service Pricing Approach –** establish an approach for unified service pricing, cost accounting, and attribution across the SCaN integrated network.
2010	**IN-1: Integrated Network Decision –** make decisions regarding the configuration and deployment of the integrated network including integrated network management, integrated service execution, and space internetworking
2011	**MR-1: SCaN responsibility for Mars Relay Communications Payload –** determine whether the SCaN Program will take responsibility for developing and/or operating the Mars Relay communications payload
2011	**TDRS-1: Exercise TDRS M, N option –** determine whether to exercise the contract option to procure an additional two third generation TDRS
2011	**LR-1: Coverage and Orbits of Lunar Relay Satellites –** determine the orbital configuration of the Lunar Relay Satellites and associated lunar vicinity coverage based on available mission requirements for exploration
2012	**MR-2: Configuration of near term Mars Relay communications payload –** determine the capability and the configuration of an integrated communications payload and support its development for the Mars Relay
2012	**NE-2: Ka-band uplink to support lunar operations –** decide if a Ka-band uplink is necessary to meet Constellation and science mission requirements
2014	**OPT-1: Lunar Trunk Line: Optical or RF Ka-band Link –** decide if the lunar relay trunk

Year	Phase 1 (2009-2015) Architecture Decision Point Descriptions
	should be implemented via optical or RF technology and define an optical IOC (if needed)
2014	**NE-3: Upgrades to Support the Lunar Trunk** – determine how to upgrade the Near Earth element to support the lunar relay space to ground link
2015	**DS-2: Deep Space 70-m Subnet Replacement** – determine the most viable option to replace the 70-m subnet
2015	**MR-3: Configuration of mid term Mars Relay communications payload –** determine the capability and the configuration of a mid-term integrated communications payload and support its development for the Mars Relay
2015	**COM-1: Internetworking Architecture Deployment –** make decisions regarding the communications protocol architecture and deployment of secure space internetworking services (DTN and IP) within the SCaN Program and between the SCaN Program and its user missions and partners

3.3 Phase 2 Evolution (2015-2018)

The deployment of the second phase of SCaN architecture evolution will enable increasingly sophisticated lunar science missions, and progressively more complex Mars and planetary science missions will also occur in this timeframe.

Phase 2 evolution will provide the following major SCaN network capability changes:

a. Near-Earth optical technology IOC using ground stations and/or relays with data rates of up to 1.2 Gbps from the Sun-Earth libration points with reduced size, weight, and power requirements for user missions

b. Optimetric measurements with ranging at the centimeter level, including Doppler-equivalent observables

c. Start of the direct replacement of the deep space 70-m capability

d. Space internetworking with DTN and IP across the Earth domain

e. Integrated network management and integrated service execution with DTN and IP management

Building on expected successes in Phase 1, the Agency will execute Mars optical relay pathfinders to enable future technology insertion. NASA will also continue to augment microwave arraying to improve the reliability and flexibility of SCaN services by enhancing soft failure and sub array capabilities. The deployment of space internetworking with DTN and IP across the SCaN architecture will provide seamless transitions between SCaN capabilities. Data confidentiality and uplink security will be implemented within the space internetwork. Transition of the separate SCaN networks to an integrated network management structure will improve end-to-end operability and cost effectiveness of network management functions for the Agency.

3.3.1 Phase 2 Architecture Decision Point Summary

Table 3-2 lists the Phase 2 ADPs and their associated descriptions.

Table 3-2. Phase 2 ADP Summary

Year	Phase 2 (2015-2018) Architecture Decision Point Descriptions
2017	**OPT-2: Mix of space- and ground-based optical systems for the Earth domain** - determine the optimum implementation mix of Earth-based optical stations and Earth-orbiting optical relays for the near-Earth domain optical communications capability
2018	**TDRS-2: Fourth Generation TDRS procurement -** decide the capabilities and schedule for the fourth generation TDRS

3.4   Phase 3 Evolution (2018-2025)

The deployment of the third phase of SCaN architecture evolution will enable sophisticated robotic science missions with hyperspectral imaging or SAR instrumentation near Mars and beyond. NASA plans to develop and launch pathfinders for deep space optical communications and tracking systems, demonstrating 100 Mbps throughput or more at one AU, and sub-meter-level ranging measurements for deep space science missions. Robust support for lunar human exploration including possible outposts, Mars exploration, and missions to outer planets will be provided. Data throughput of at least 100 Mbps from Mars via highly available trunk lines and a dedicated (or improved) Mars relay system will dramatically increase exploration efficiency around the red planet. Size, weight, and power requirements for missions will be significantly reduced, as optical communications capabilities evolve. Space internetworking with DTN and IP will be extended throughout the solar system. NASA will continue enhancements of the LR portion of the SCaN architecture and retirement of aging or obsolete microwave systems (such as the 70-m antennas) in this phase.

3.4.1   Phase 3 Architecture Decision Point Summary

Table 3-3 lists the Phase 3 ADPs and their associated descriptions.

Table 3-3. Phase 3 ADP Summary

Year	Phase 3 (2018-2025) Architecture Decision Point Descriptions
2020	**MR-4: Configuration of long term Mars Relay communications payload** - determine the capability and the configuration of a long-term integrated communications payload and support its development for the Mars Relay
2020	**OPT-3: Mars trunk decision** - decide if the Mars Relay trunk should be implemented via optical or RF technology and define the deep space domain optical IOC implementation (if needed)
2022	**OPT-4: Mix of space- and ground-based optical terminals for the deep space domain** - determine the optimum mix of space relay and Earth-based ground terminals for the deep space optical capability

4. Summary

The SCaN Program has defined an integrated network architecture that fully meets the Administrator's mandate to the Program, and will result in a NASA infrastructure capable of providing the needed and enabling communications services to future space missions. The integrated network architecture will increase SCaN operational efficiency and interoperability through standardization, commonality and technology infusion. It will enable NASA missions requiring advanced communication and tracking capabilities such as:

a. Optical communication

b. Antenna arraying

c. Lunar and Mars Relays

d. Integrated network management (service management and network control) and integrated service execution

e. Enhanced tracking for navigation

f. Space internetworking with DTN and IP

g. End-to-end security

h. Enhanced security services

Moreover, the SCaN Program has created an Integrated Network Roadmap that depicts an orchestrated and coherent evolution path toward the target architecture, encompassing all aspects that concern network assets (i.e., operations and maintenance, sustaining engineering, upgrade efforts, and major development). This roadmap identifies major NASA ADPs, and shows dependencies and drivers among the various planned undertakings and timelines. The roadmap is scalable to accommodate timely adjustments in response to Agency needs, goals, objectives and funding.

Future challenges to implementing this architecture include balancing user mission needs, technology development, and the availability of funding within NASA's priorities. Strategies for addressing these challenges are to: define a flexible architecture, update the architecture periodically, use ADPs to evaluate options and determine when to make decisions, and to engage the stakeholders in these evaluations. In addition, the SCaN Program will evaluate and respond to mission need dates for technical and operational capabilities to be provided by the SCaN integrated network. In that regard, the architecture defined in this ADD is scalable to accommodate programmatic and technical changes.

Appendix A. Abbreviations and Acronyms

Acronym	Definition
ADD	Architecture Definition Document
ADP	Architecture Decision Point
AMPM	Agency Mission Planning Manifest
AU	Astronomical Unit
CCSDS	Consultative Committee for Space Data Systems
CLTU	Command Link Transmission Unit
CR	Change Request
Cx	Constellation
CxP	Constellation Program
DSN	Deep Space Network
DTN	Disruption Tolerance Network(ing)
ESMD	Exploration Systems Mission Directorate
GEO	Geosynchronous Earth Orbit
IEEE	Institute of Electrical and Electronic Engineers
ILN	International Lunar Network
IOAG	Interagency Operations Advisory Group
IOC	Initial Operational Capability
IP	Internet Protocol
IRD	Interface Requirement Document
ISS	International Space Station
JDEM/IDECS	Joint Dark Energy Mission/International Dark Energy Cosmology Survey
JWST	James Webb Space Telescope
L2	Lagrange point that lies on the line defined by two large masses (e.g., (Earth/Sun or Earth/Moon), beyond the smaller of the two where the gravitational forces of the two large masses balance the centrifugal force on the smaller mass

Acronym	Definition
LEO	Low Earth Orbit
LDPC	Low Density Parity Check
LR	Lunar Relay
LRO	Lunar Reconnaissance Orbiter
LRS	Lunar Relay Satellites
MAVEN	Mars Atmosphere and Volatile EvolutioN
MEJI	Mars Exploration Joint Initiative
MEO	Middle Earth Orbit
MOC	Mission Operations Center
MR	Mars Relay
MSL	Mars Science Laboratory
NASA	National Aeronautics and Space Administration
NEN	Near Earth Network
NISN	Network Integrated Services Network
NPD	NASA Policy Directive
NPR	NASA Procedural Requirement
O&M	Operations & Maintenance
OCIO	Office of Chief Information Officer
OP	Outer Planet
PA&E	Program Analysis and Evaluation Office
PCA	Program Commitment Agreement
PP	Program Plan
RF	Radio Frequency
SAR	Synthetic Aperture Radar
SCaN	Space Communications and Navigation
SCMM	Space Communication Mission Model
SDR	Software Defined Radio
SGSS	SN Ground System Sustainment
SE&I	Systems Engineering & Integration

SCaN-ADD-V1
Revision 1

Acronym	Definition
SEMP	System Engineering Management Plan
SMC	Strategic Management Council
SMD	Earth Science Mission Directorate
SN	Space Network
SRD	System Requirements Document
TASS	TDRSS Augmentation Services for Satellites
TDRS	Tracking & Data Relay Satellite
TDRSS	Tracking & Data Relay Satellite System
TRL	Technical Readiness Level
TT&C	Tracking, Telemetry & Command
U.S.	United States