SCaN-ADD-V1

SPACE COMMUNICATIONS AND NAVIGATION PROGRAM

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

Revision 4

Effective Date: April 7, 2014

Expiration Date: April 7, 2019

National Aeronautics and Space Administration

NASA Headquarters
Washington, D. C.

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Effective Date: April 7, 2014

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04/7/2014

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Preface

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Change Information Page

List of Effective Pages	
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ii through v	Revision 4
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4-1	Revision 4
A-1 though A-5	Revision 4

Document History

Document Number	*Status/Issue*	*Effective Date*	*CR Number*
SCaN-ADD-V1	Baseline	April 20, 2009	CR000026
SCaN-ADD-V1	Revision 1	January 28, 2010	CR000049
SCaN-ADD-V1	Revision 2	October 31, 2011	CR000066
SCaN-ADD-V1	Revision 3	January 14, 2013	CR000078
SCaN-ADD-V1	Revision 4	April 7, 2014	CR000094

Change History

Revision	*Effective Date*	*Description of Change*
Baseline (CR000026)	April 20, 2009	Initial Release
Revision 1 (CR000049)	January 28, 2010	Changes to align with new SCaN integrated architecture vision
Revision 2 (CR000066)	October 31, 2011	Changes to align with recent SCaN changes and with ADD Volume 2
Revision 3 (CR000078)	January 14, 2013	Changes to align with Architecture Assessment and programmatic decisions
Revision 4 (CR000094)	April 7, 2014	Updated to reflect ADM-3, ADM-3a, 2013 Roadmap Workshop conclusions, and latest programmatic directions

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Section 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 user mission platforms (such as space vehicles); deriving information from transmitted signals for tracking, position determination, and timing; and measuring the Radio Frequency (RF) emission of or reflection from celestial bodies.

This document, i.e., Volume 1 of the SCaN Network Architecture Definition Document (ADD), provides a high-level summary description of the NASA SCaN 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 and 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 (SOMD) (now the Human Exploration and Operations Mission Directorate (HEOMD)). 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 SCaN driving requirements which are consistent with NASA Policy Directive (NPD) 8074.1, Management and Utilization of NASA's Space Communication and Navigation Infrastructure. The driving requirements specified in the SCaN Program Commitment Agreement (PCA) are:

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 evolve to 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 Program Plan. As part of the SCaN system engineering process, SCaN has defined a set of program Level 2 requirements in the SCaN Network System Requirements Document (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 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 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 descriptions of the target architectures of the integrated network are described in the ADD Volume 2 for Phases 0 & 1, and Volume 3 for Phase 2. Other ADD volumes will be added as needed. 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 ADD volumes 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 four phases that roughly correspond to the following time periods:

Phase 0: The Independent Networks Phase represents the SCaN Network as it existed in 2010. In this phase, three networks and their supporting functions were independent and the definition of the subsequent phases began.

Phase 1: The Pre-Integrated Network Phase represents the SCaN Network with three independent networks, but with new capabilities that extend the functionality of the networks and address upcoming user mission needs. Furthermore, these new capabilities lay the groundwork for the next phase by beginning the implementation of key features of the Integrated Network, including standardized services and interfaces.

Phase 2: The Integrated Network Phase represents the SCaN Network after the three networks are upgraded into a unified communications and navigation infrastructure. The SN, NEN, and DSN will be modified to share a common architecture presenting interoperable, standardized services to user missions. A unified process will be established to make commitments to user missions for providing the services that they require.

Phase 3: The Post-Integrated Network Phase represents the next evolutionary step in the SCaN Network. New technologies like space internetworking and optical communications will be infused as required to answer the needs of NASA's long-term exploration and science goals. Major objectives are to change the architecture to enable significant reductions in system acquisition and operations costs while improving the SCaN Network's flexibility and scalability to be more responsive to changes in budget and user needs.

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 Independent Program and

Cost Evaluation Office (IPCE). 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 evolutionary path of the SCaN Network. Section 3 contains a summary of the ADPs and their expected need dates. The SCaN Program will perform technology development activities and 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, the terrestrial networks operated by the Communication Service Office (CSO) under the OCIO (the CSO Networks, formally known as NISN), are 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. The SCaN Program performs user mission navigation as a cost reimbursable service. Aside from user mission interfaces, the architecture described in this document does not include details regarding user mission space or ground system elements. The ADD may include details of external elements if necessary to describe the SCaN architecture (i.e. a hosted communications relay)

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 (SEMP) and the SCaN Program Management Plan (PMP).

1.6 Document Overview

Volume 1 of the SCaN 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

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 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

1.8 Document Convention and Notation

To distinguish between the networks as systems and the organizational entities that currently operate the networks, this document uses new terminology to refer to the systems that comprise the SCaN Network. The set of organizational elements managed by Goddard Space Flight Center (GSFC) that are required to operate and maintain the SN is known as the *Earth-Based Relay Element* (EBRE). Examples of organizational entities that are included in the EBRE include the SN project, the Network Integration Management Office (NIMO), and functions of the Flight Dynamics Facility (FDF) that are required to operate the Tracking and Data Relay Satellite System (TDRSS) fleet. The set of organizational elements managed by Goddard Space Flight Center that are required to operate and maintain the NEN is known as the *Near Earth Element* (NEE), including the NEN Project and NIMO. The set of organizational elements managed by the Jet Propulsion Laboratory (JPL) that are required to operate and maintain the DSN is known as the *Deep Space Element* (DSE) and includes the DSN project and the DSN Mission Services Planning & Management Office (DMSP&M). These new terms (EBRE, NEE, and DSE) will be used exclusively in this document, as well as the SCaN SRD and SCaN ConOps. Each element may contain development projects, such as the EBRE's SN Ground System Sustainment (SGSS) Project and the Tracking and Data Relay Satellite (TDRS) K/L/M Project. Each element is responsible for the architecture of their respective development projects. Future development projects may be independent of the current elements, and will develop their own documentation to describe their architecture and interfaces with the SCaN Network. In Phase 2, NIMO and DMSP&M are reorganized into the SCaN Mission Commitment Office (MCO), which operates the new *Customer Service Management Element* (CSME). EBRE, NEE, and DSE will continue to operate the SN, NEN, and DSN, respectively. In Phase 2, EBRE, NEE, and DSE are referred to as Operational Network Elements (ONEs). Common equipment and software will be developed and deployed to the EBRE, NEE, DSE and CSME.

For purposes of this document, dates associated with elements that are funded and have program-planned dates, are externally imposed milestones, or are 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.

Section 2. SCaN Network Architecture Overview

The SCaN 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 defined in the SCaN PCA and NPD 8074.1: Management and Utilization of NASA's Space Communication and Navigation Infrastructure. Central to this architecture is a baseline set of core services, as shown in Figure 2-1, that are provided by all of the SCaN Network assets to user missions. These services are standardized and provided by common interfaces across the SCaN Network.

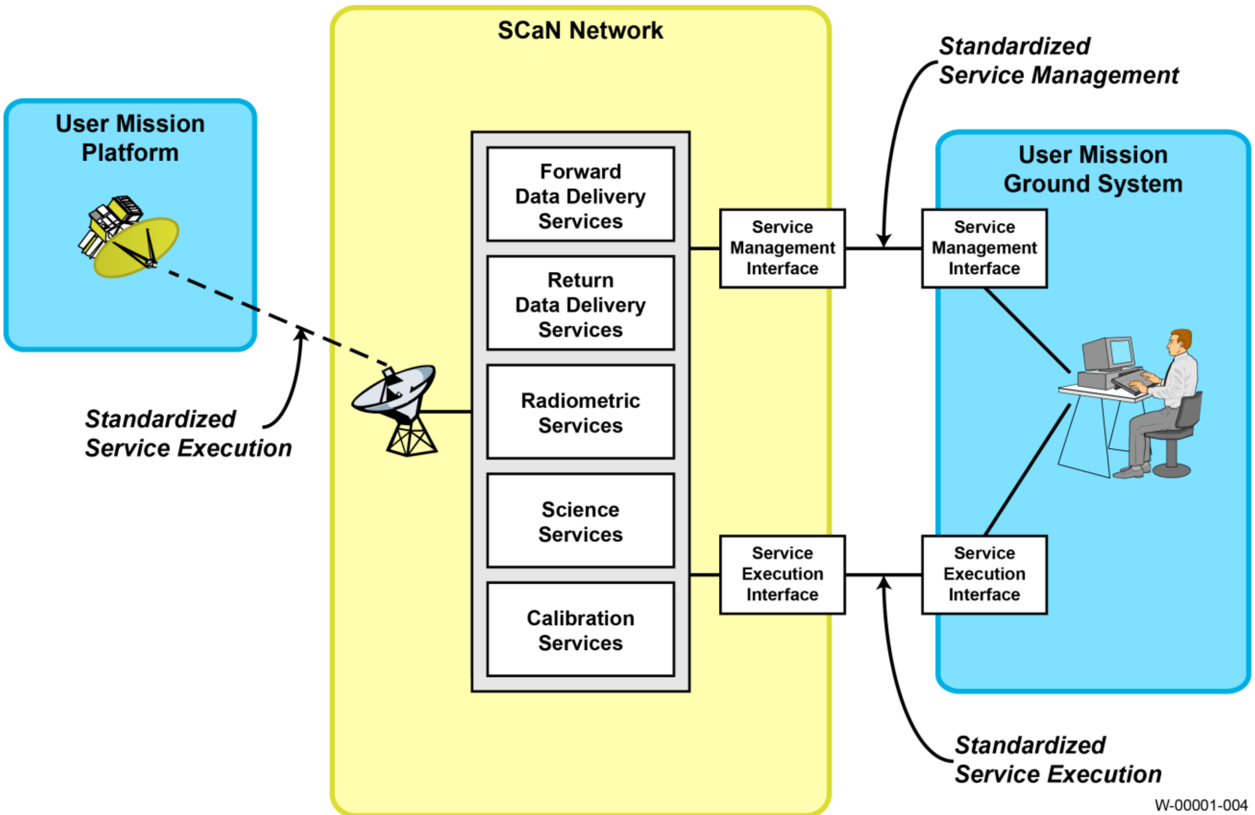

Figure 2-1. SCaN Network Standard Services

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, such as those 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 RF baseline (i.e., Phase 3 for near Earth and 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 starting in Phase 1 and full integration of the networks by the end of Phase 2

d) Development of a Destination Relay capability for exploration and science missions 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)

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

h) Compatible with existing user missions and legacy interfaces

The following sections contain a summary of the Phase 0 “As-Is” SCaN network, 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 SCaN Integrated Network architecture, including its services, operational concepts, and future capabilities.

2.1 SCaN Phase 0 Network

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) **EBRE (i.e. the SN)** – constellation of geosynchronous relays (TDRS) and associated ground systems

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

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

Each of these networks is 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, forward and return data delivery, RF science, radiometric, 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 Phase 0 NASA space communication networks, i.e., EBRE, NEE, and DSE, have been evolving independently for as long as four decades on their own respective paths, providing 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 exploration and science user missions that will require services from all three networks.

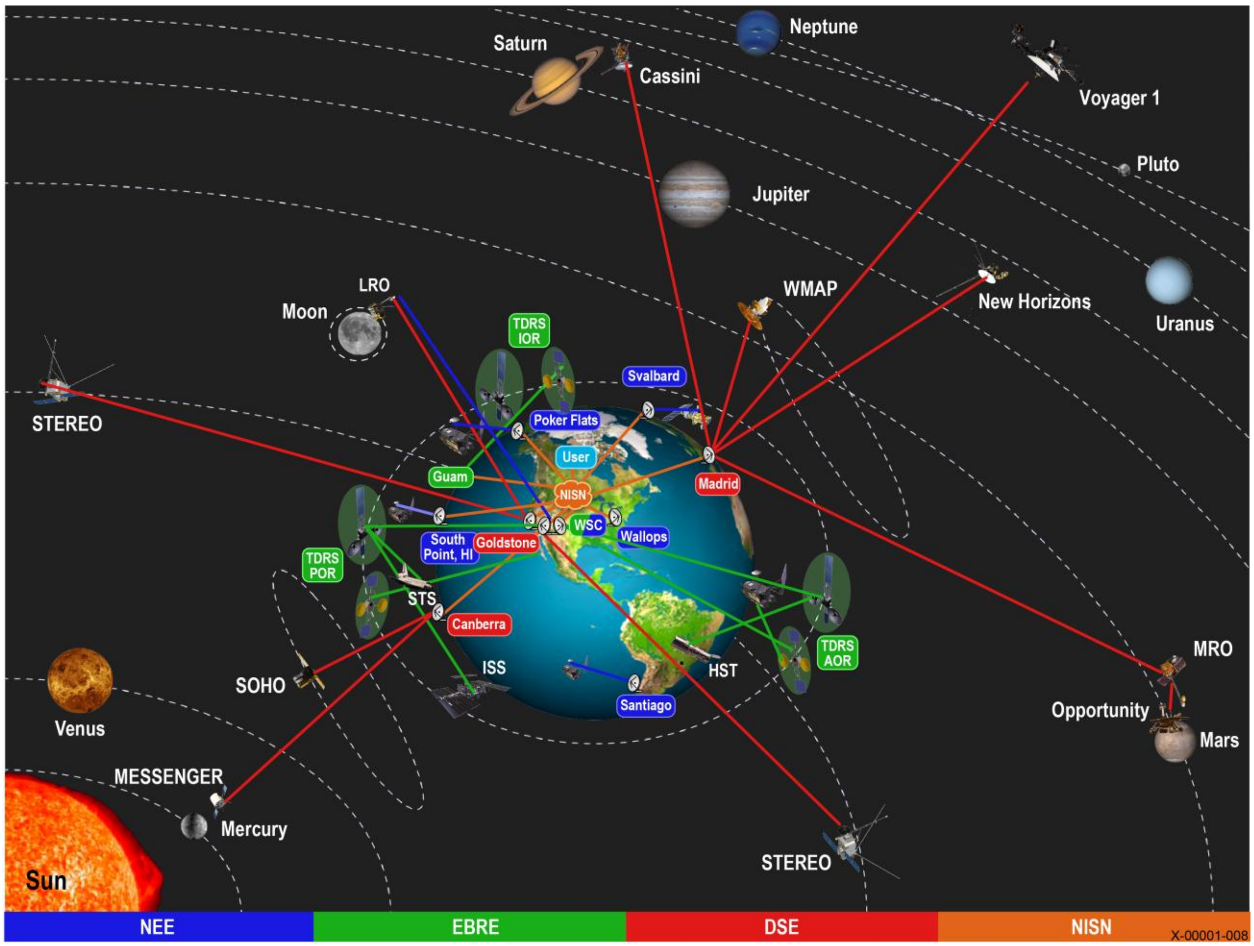

Figure 2-2. SCaN Phase 0 Network Architecture

2.2 Drivers/Requirements Flow down to Capabilities

Figure 2-3 shows the SCaN driving 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, standard service interfaces, and integrated service execution. It also includes new technologies such as antenna arraying, optical communications, and new navigation capabilities, and also 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 Network assets, cooperating national and international networks, and compatible space assets. These new capabilities are necessary to efficiently execute future science and exploration missions.

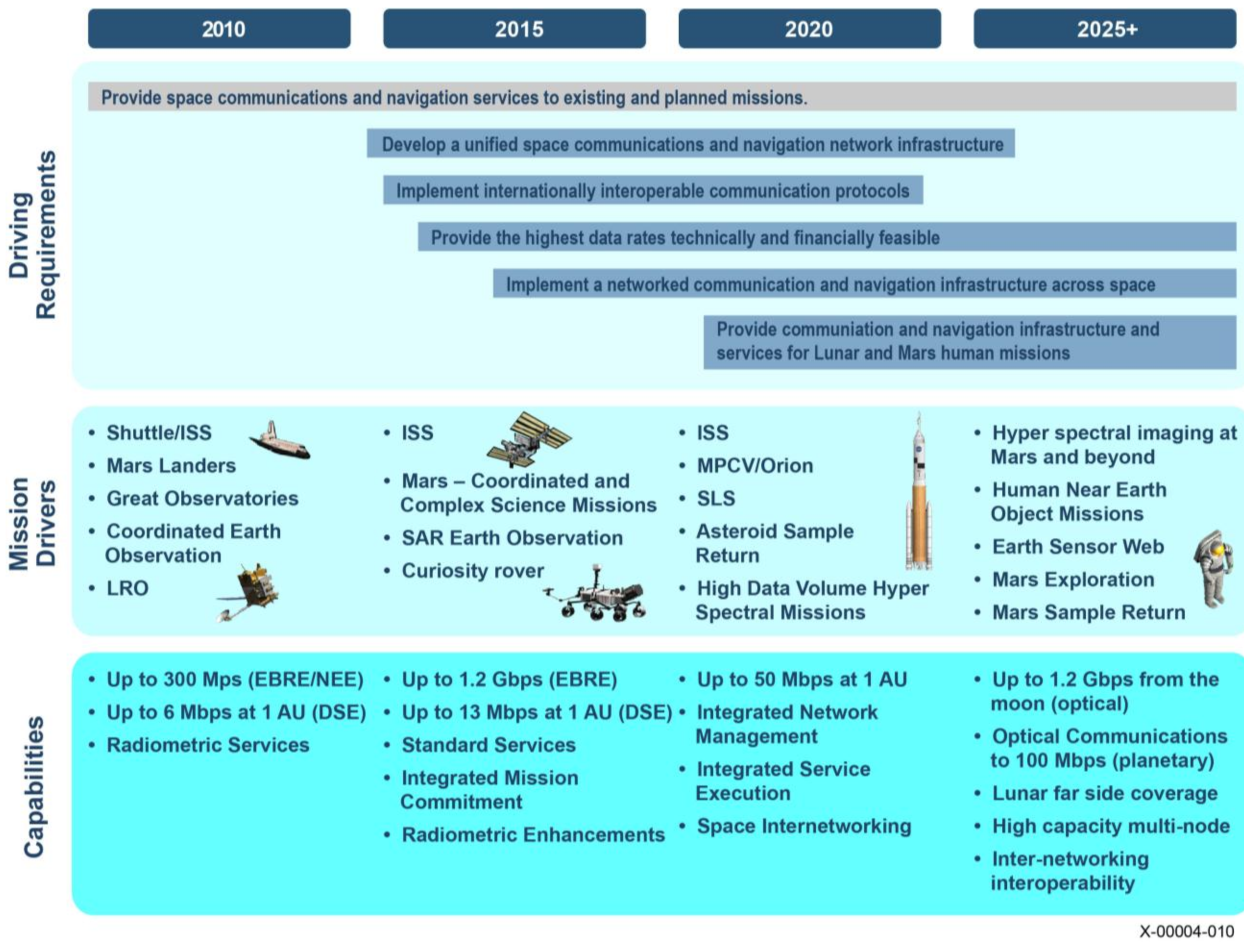

Figure 2-3. Requirements & Mission Phasing, Capabilities Flow

2.3 SCaN Network Architecture in Phases 2 and 3

The vision for the future SCaN Network 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.

The future SCaN Network architecture, as illustrated in Figure 2-4, unlike 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, and is referred to as the SCaN Integrated Network. 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 security measures for managing access control and ensuring confidentiality, system integrity, and availability.

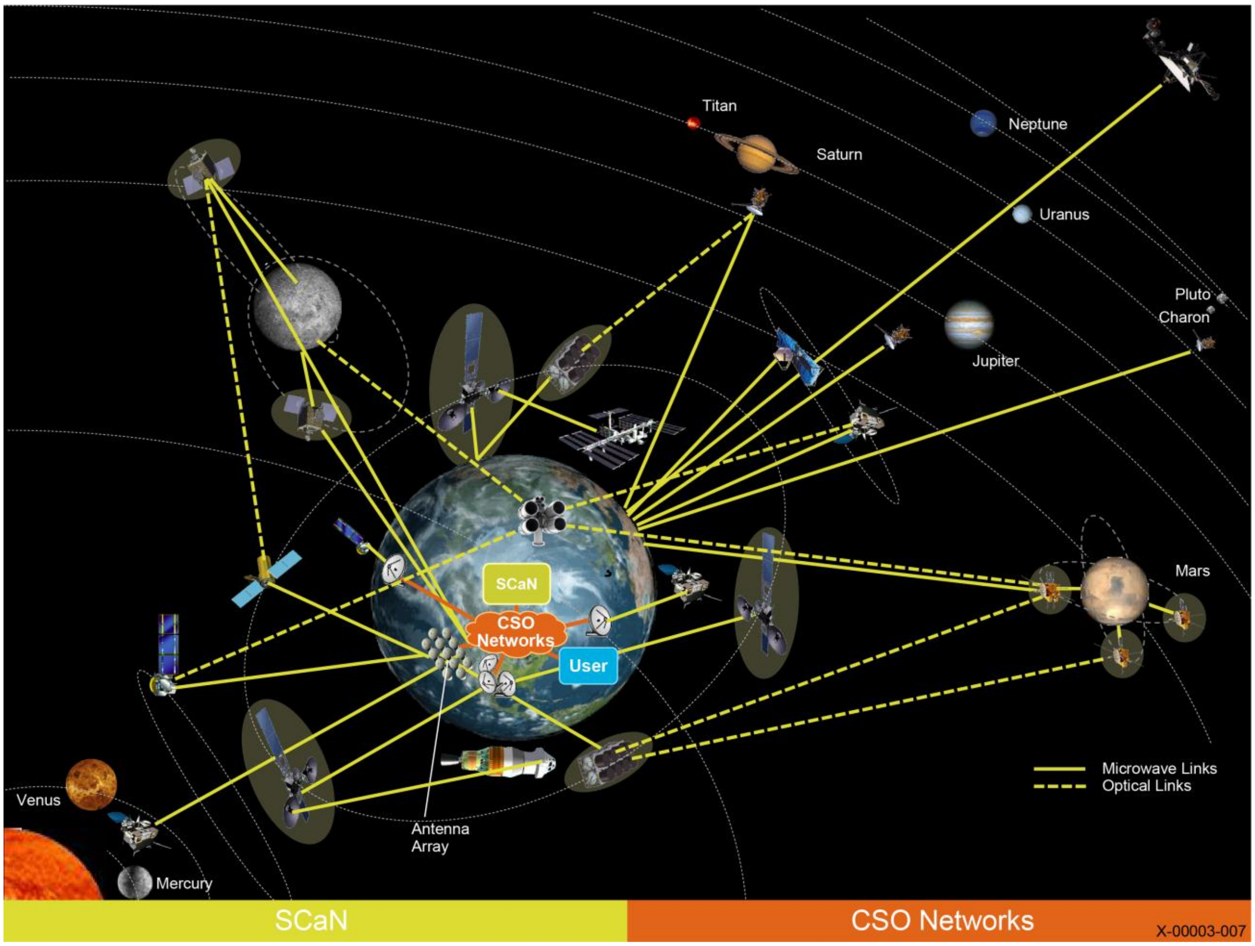

Figure 2-4. SCaN Phase 3 Network Architecture (circa 2025)

The future SCaN Network 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) New technology (optical, arraying, SDR) infused into the SCaN Network

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 data 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 commonly 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. 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 SCaN 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[1]. 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 SCaN Network will transition into an integrated network service architecture in Phase 2 and continuing into Phase 3 and beyond, illustrated in Figure 2-5, providing SCaN customers with the capabilities to seamlessly use any of the available SCaN assets to support their missions. It will also allow the SCaN Program to optimize the application of its assets to efficiently meet the collective needs of Agency missions. The service-based architecture will include: common services; common processes for network assets and user missions; internationally interoperable,

[1]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.

standard services; and integrated network management and data delivery elements to maximize access to all of the SCaN Program's capabilities.

The Phase 3 integrated network service architecture shown in Figure 2-5 will include the network assets of NASA's current EBRE, NEE, and DSE as well as future expansions, and includes CSME added in Phase 2. These assets are shown grouped by mission domain. As with the current NEN, the Near Earth Element of the SCaN Network will include both NASA-owned ground stations and contracted commercial stations. The figure shows separately the assets of other agencies and of commercial vendors not under contract to the SCaN Network. The use of internationally interoperable, standard services will enable user missions to interface seamlessly to the SCaN Network as well as these external entities. SCaN may interface with other agencies via the standard service management and execution interfaces. User Mission Ground Systems 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 all assets of the SCaN Network. The SCaN Program will publish a standard catalog of services and ensure secure access to services via a consistent set of interfaces for planning, requesting, delivering, managing and reporting.

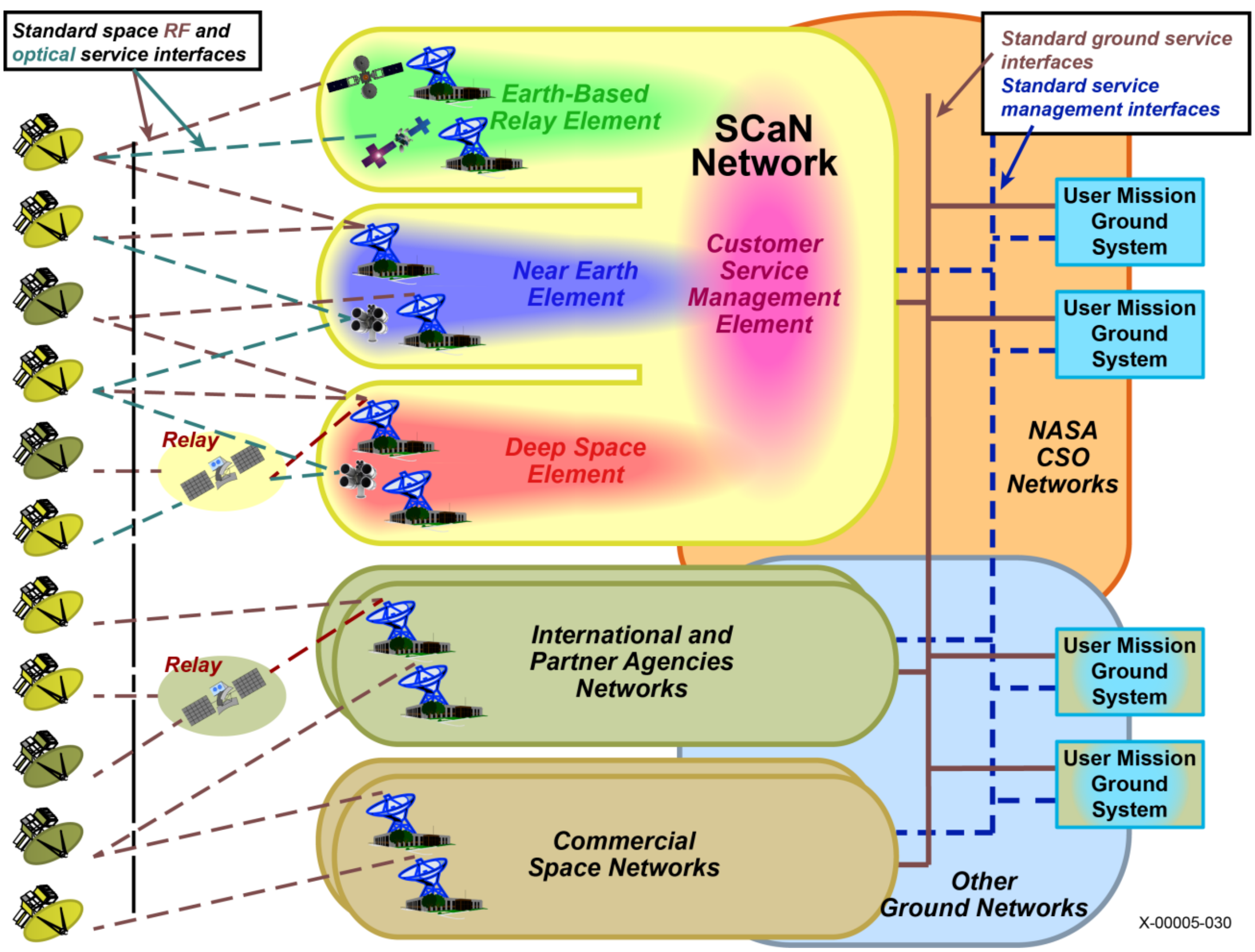

Figure 2-5. SCaN Phase 3 Service Architecture

SCaN Network services are categorized as follows:

a) **Forward Data Delivery Services** transmit the data received from the user mission ground system to the user mission platform. Data transmitted typically are commands, sequence loads, and flight software loads, but may also include any other types of data elements. Corresponding to the various levels of data units processed and radiated, different service types have been defined for this service group in Phase 2. They are Command Link Transmission Unit (CLTU), frame, file, and IP service.

b) **Return Data Delivery Services** acquire the data transmitted by the user mission platform over the space link and deliver them to the user mission ground system. Corresponding to the various levels of data units processed and delivered, different service types have been defined for this service group in Phase 2. They are beacon tone, return all frames, return channel frames, packet, file, and IP service.

c) **Radiometric Services** provide radiometric observables from which the position and velocity of the user mission platform can be derived. Three types of service have been defined for this service group in Phase 2. They are Raw Radiometric Data service, Validated Radiometric Data service, and Delta Differential One-way Ranging (Delta-DOR) service.

d) **Science Services** use the assets available in the SCaN Network to provide measurements on celestial bodies and characterize the intra-solar system media. These services include radio science, radio astronomy and radar science in Phase 2.

e) **Calibration Services** provide more precise Earth Orientation Parameters (EOP) referenced to the terrestrial and celestial frames, and adjustments to signal delays due to the Earth's troposphere and ionosphere.

SCaN will continue to provide legacy services (such as Return Bitstream) to existing user missions. See the SCaN Service Catalog for detailed service descriptions. These service definitions, particularly Forward and Return Data Delivery Services, may have to be refined as SCaN adds capability in Phase 3. For example, Phase 3 may include data delivery from one user mission platform (such as a astronaut or rover) through a SCaN relay to another user mission platform (such as a exploration vehicle or habitat). Such data delivery service does not currently fit the current definitions.

2.4.1 Integrated Network Management

The SCaN 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 2-5) that will provide access to all of the services provided by the SCaN 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 Phase 3 capabilities such as the Destination and Mars Relays and optical communication (relays are described in Sections 2.6.3 and 2.6.4). The integrated network management interface will provide user missions with a set of standard service management functions, 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.

2.4.1.1 Mission/Program Drivers

In particular, exploration 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
   1. Service planning
   2. Service request scheduling
   3. Service accountability reporting

b) Common network control functions
   1. Network scheduling
   2. Network asset configuration and control
   3. Network asset monitoring
   4. Space Internetworking management

c) SCaN Service Catalog accessible at the network management interface

2.5 SCaN 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 EBRE, NEE, and DSE 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 additional 34-m antennas in the DSN Aperture Enhancement (DAE) Project.

By the end of Phase 2 all of the existing SCaN networks will be completely integrated into 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 end state of the Phase 2 Integrated Network is still being refined as a result of architecture trade studies and analyses. Architecture Decision Memorandum-2 (ADM-2), released after the November 2011 SCaN Phase 2 Architecture Assessment, documents the management positions and decisions, including that the "Phase 2 development should be based on an incremental development approach." ADM-3a documented the decision that a new CSME will be established to integrate the functions of the GSFC NIMO and JPL DMSP&M. ADM-3a also splits Phase 2 into Phase 2a that implements CSME and completes upgrades to support early exploration missions and Phase 2b that completes the network integration.

The introduction of relay assets, such as the Destination Relay and space internetworking nodes, into the SCaN Network in Phase 3 will extend SCaN services beyond line of sight from Earth, and will be a major addition to the SCaN operational concept. The relay assets will provide interfaces to the surface elements developed by other directorates, and will provide high-rate communications and high-precision navigation services for regions out of line-of-sight of Earth, filling a coverage gap. Operational details of the Destination Relay assets within the SCaN Program are still being refined, as upcoming mission architectures and requirements are defined. A Space-Based Relay (SBR) will become operational in Phase 3. The SBR will augment/replace the TDRSS as the first and second generation satellites are retired. The capabilities for the SBR are still in definition, but will include optical communications.

Optical terminals and optical relay services will have some different operational considerations when compared to today's RF ground and relay systems. Optical systems will require more rigorous pointing, acquisition, and tracking due to the smaller beamwidth and 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. A combined RF/Optical system may be employed to help mitigate some of these issues.

The concept of operations for Phase 3 builds upon the previous capabilities in various additional ways including: support of a possible human exploration outpost, support of a possible human mission to a Near Earth Object (NEO), 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 human exploration outpost or NEO campaign 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 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 Phase 3 orbiting relays, however, could eliminate the weather-induced operational challenges encountered with Phase 2 Earth-based optical systems if a RF downlink is employed.

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, L, and M, and the completion of SGSS by the end of Phase 1. For the deep space domain, activities include the DAE Project with additional 34-m antennas with arraying capability starting in Phase 1 and migration to higher frequencies (such as Ka-band) extending through Phase 3. New capabilities will also be required to support the new human spaceflight missions in late Phase 2 and Phase 3.

2.6.1 Enhanced Near Earth Domain Capability

The near Earth domain, shown in Figure 2-6, encompasses operational assets serving user mission platforms on and near the Earth, up to lunar and Sun-Earth Lagrange distances. The mission/program drivers for changes in this capability are described below.

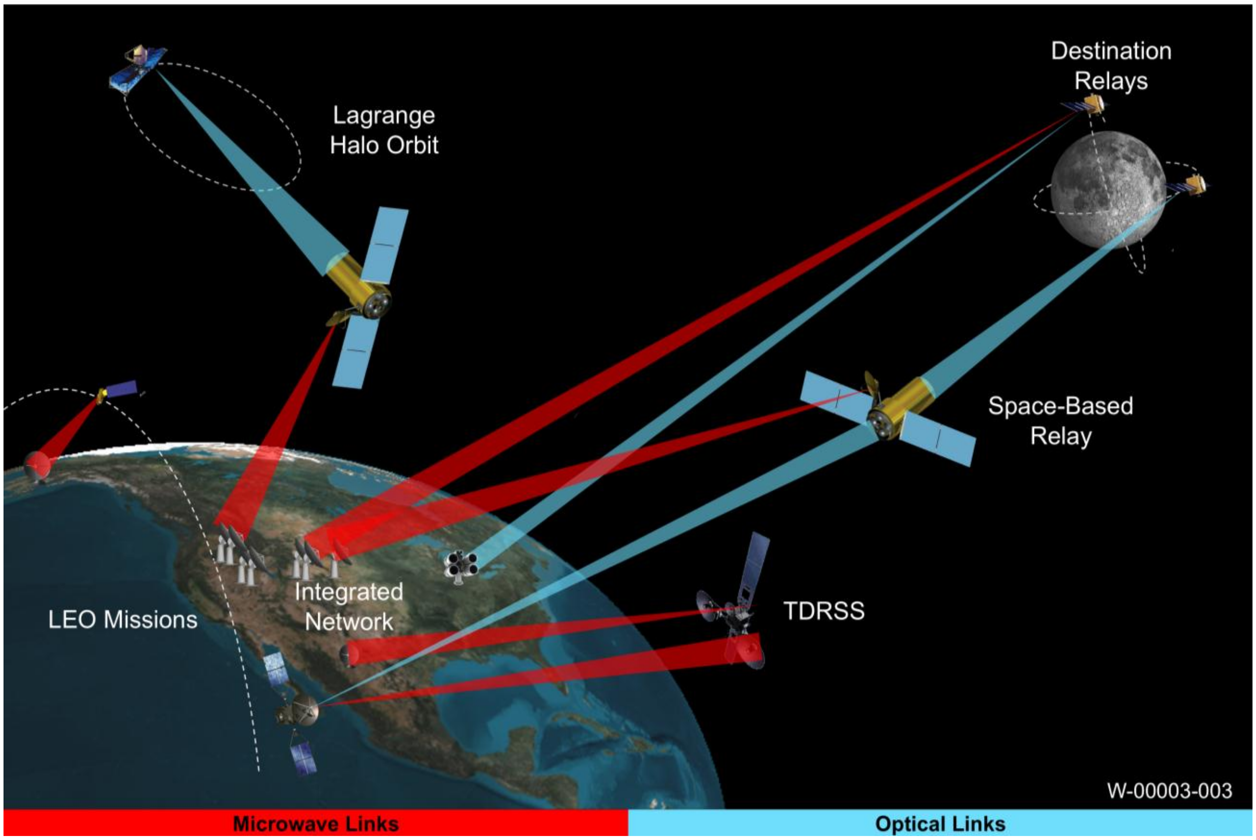

Figure 2-6. Enhanced Near Earth Domain Capabilities

2.6.1.1 Mission/Program Drivers

Science missions such as Soil Moisture Active Passive (SMAP) are near-term drivers that require high-rate return links in earth orbits. Human exploration missions require: robust communication for human flight/safety, high rate trunk lines, near continuous tracking coverage, and seamless user mission support by all of the SCaN Network assets. Science spacecraft such as the James Webb Space Telescope (JWST) and the Wide-Field Infrared Survey Telescope (WFIRST) require high-rate science data return at Sun-Earth Lagrange Point 2 (L2) distance. Other mission types such as large format imagers, Synthetic Aperture Radars (SAR), Lagrange point and Earth-orbiting sensor webs will benefit from high data rate downlinks and space internetworking.

2.6.1.2 Infrastructure Enhancements

Planned 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 upgrades

    1. Additional ground stations

    2. Ka-band upgrades

d) TDRSS

    1. TDRS K, L, and M
    2. Multiple aperture arraying

e) SGSS

f) Blossom Point Ground Terminal (BPGT)

g) Launch Communications Stations (LCS)

h) Space-Based Relay

i) Destination Relay

j) Integrated Network Management and Integrated Service Execution

k) Space internetworking nodes with IP and DTN

2.6.1.3 Performance

Within the near Earth domain, the near Earth optical IOC (*2022*) 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 SCaN Network.

2.6.2 Enhanced Deep Space Domain Capability

Through system upgrades and insertion of antenna 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 2-7). 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.

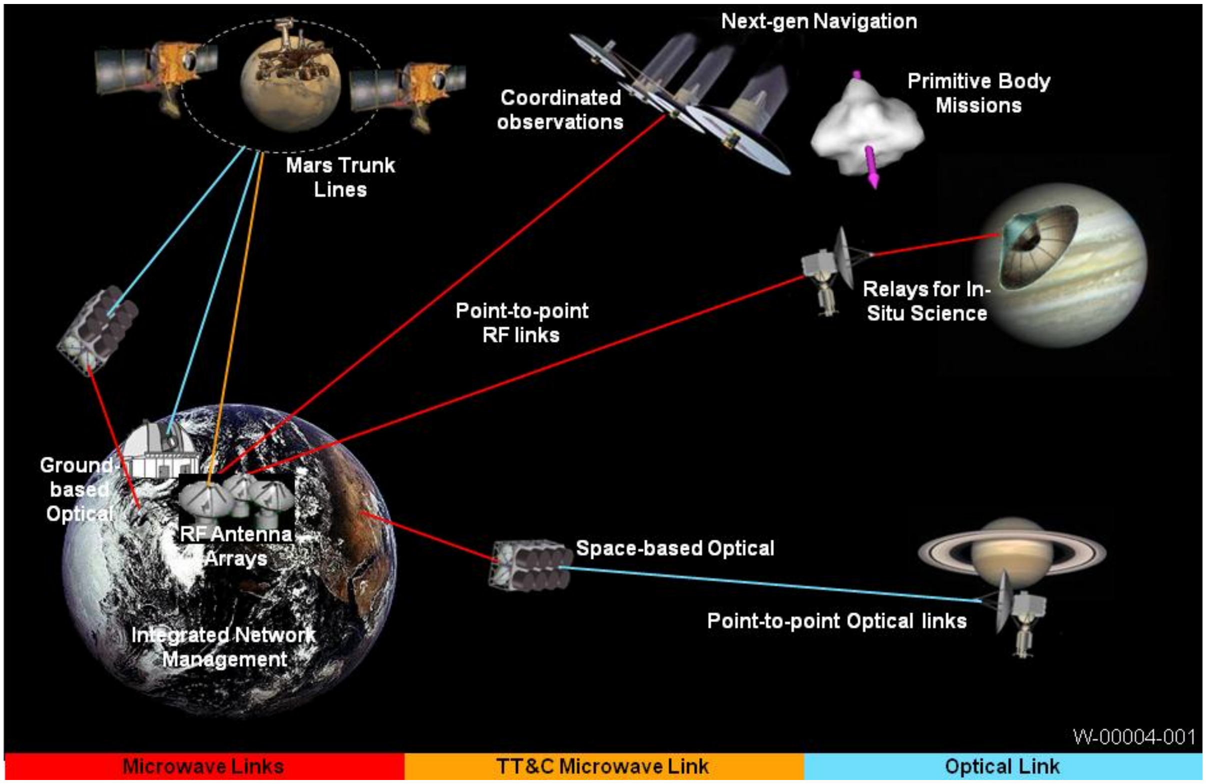

Figure 2-7. Enhanced Deep Space Domain Capabilities

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; Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight), which needs the MR and high-rate trunk line; Outer Planet missions 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 Tracking, Telemetry & Command (TT&C). Many of these missions will be collaborative ventures with European or other international agencies.

2.6.2.2 Infrastructure Enhancements

Planned Infrastructure enhancements include:

a) Optical IOC: flight and ground terminals

b) Deep space optical relay for higher availability

c) RF ground stations

   1. Additional 34-m antennas with arraying capability from the DAE Project

   2. Capacity and performance upgrade

d) Integrated Network Management and Integrated Service Execution

e) Space internetworking nodes with DTN

2.6.2.3 Performance

The deep space communication capability will continue to provide robust standard services 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 of the electronics to solar energetic particle events. Pathfinder missions will be used to mature the technology and evaluate these potential constraints.

2.6.3 Destination Relay Capability

The introduction of Destination Relay assets into the SCaN Integrated Network will significantly increase SCaN services to user missions at lunar and NEO distances and beyond. The configuration, evolution, and destination of these relay assets within the SCaN architecture are based on emerging communication and navigation requirements of NASA exploration and science missions, as well as SCaN Program driving requirements. The relay architecture, shown in Figure 2-8, shows trunk links between Earth and relay assets using RF and/or optical technologies, as well as orbit-to-surface links. The introduction of Destination Relay assets into the SCaN Network architecture will respond to NASA's exploration and science mission plans. The termination point of the SCaN architecture resides at the interface from the Destination Relay to user mission surface and orbiting elements.

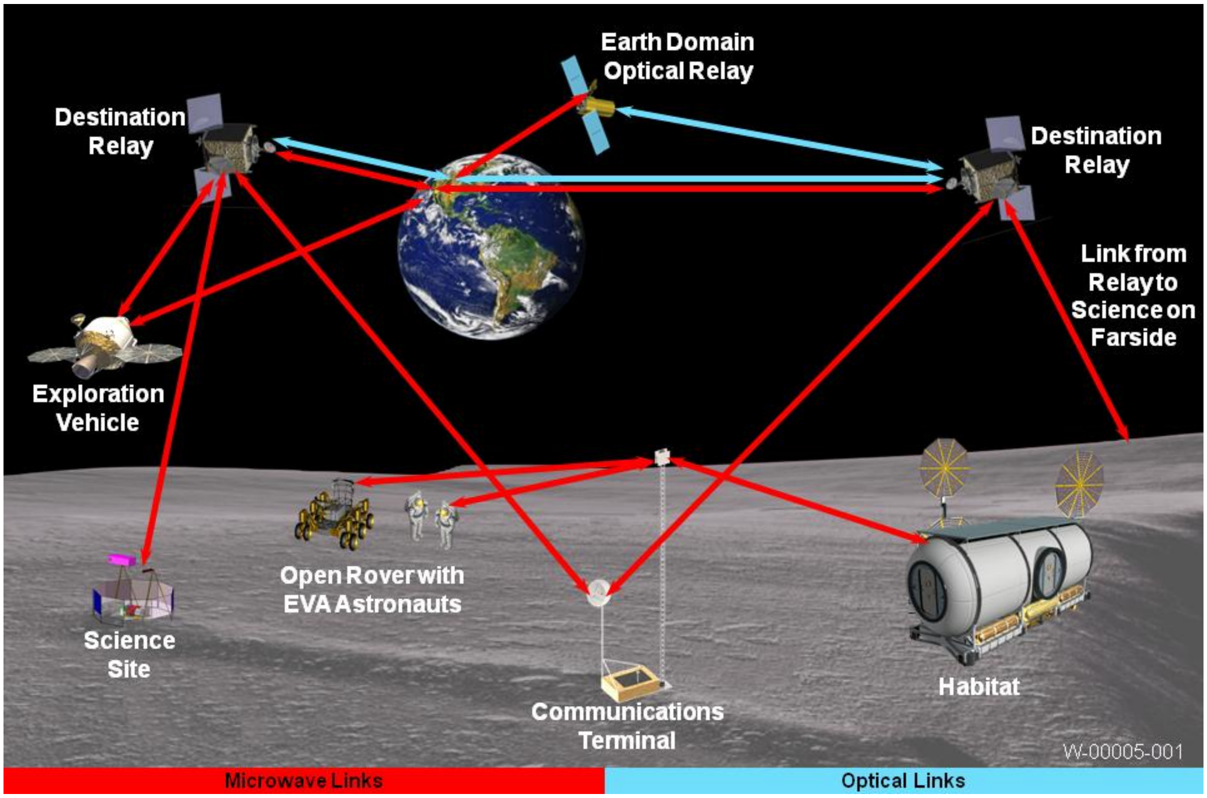

Figure 2-8. Destination Relay Capability (Lunar option)

2.6.3.1 Mission/Program Drivers

The primary driver for the Destination Relay capability is high data rate return for potential human exploration missions in Phase 3.

2.6.3.2 Infrastructure Enhancements

Planned Infrastructure enhancements include:

a) Optical IOC: flight and ground terminals

b) Earth-orbiting optical relay for higher availability

c) Destination Relay satellites

d) Space internetworking nodes with IP and DTN

e) Integrated Network Management and Integrated Service Execution

2.6.3.3 Performance

The Destination Relay architecture will be scalable to provide varying coverage depending on customer requirements, the number of orbital assets, and selected geometry. The Destination Relay assets will provide high-rate forward and return capabilities via RF and optical links, as well as radiometric capabilities for precision approach and landing and support of surface roving.

The Destination Relay assets will enable international and commercial collaboration and interoperability, and will also provide multiple access communications techniques and protocols to provision simultaneous communications to multiple 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 may continue use of relay communications payloads on science orbiters, or use dedicated relay satellites with store-and-forward, space internetworking, and system capabilities evolved from the early MR designs (see Figure 2-9). 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.

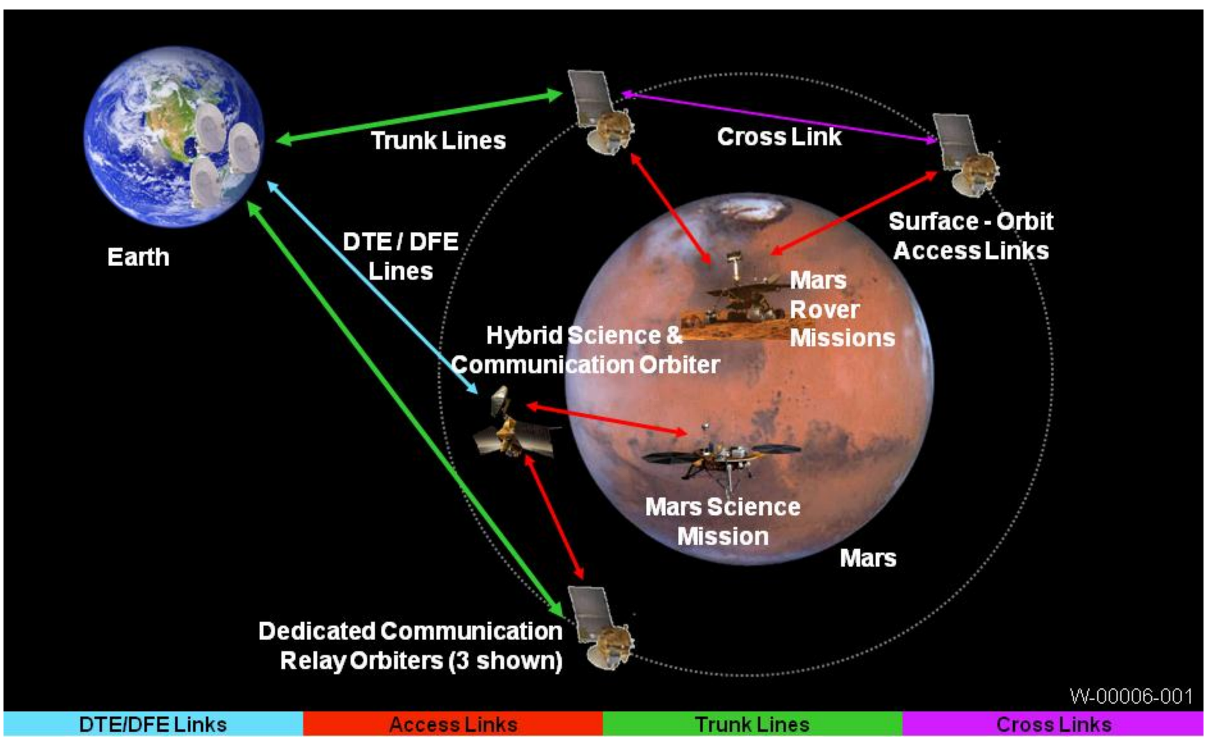

Figure 2-9. Mars Relay Capability

2.6.4.1 Mission/Program Drivers

The near-term primary drivers for the MR are the upcoming missions to Mars, which include: Mars Science Laboratory (MSL) (long distance rover), MAVEN (extends reliable communications for Mars Relay), InSight, 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 possible beyond the Phase 3 timeframe, which could drive 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 international standards such as 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 amongst 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 future SCaN 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 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 include inertial stabilization and space-based photon counting receiver technologies, which will enable the Earth-orbiting optical relay satellites. Adaptive and lightweight optics technologies will enable the deep space optical communications IOC. SDR technologies will be needed to facilitate the Destination Relay implementation. The SCaN Program’s Spectrum function obtained an additional frequency allocation in the 22 GHz band, and will 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 will enable the SGSS modernization efforts. The SCaN Standards group is developing a suite of internationally approved communications standards, including IP over CCSDS, DTN, Low Density Parity Check (LDPC) Codes, and multiple access standards to enable international collaboration and interoperability. The SCaN Program will use these and other international standards to further support network integration, space internetworking, and human exploration missions.

Section 3. SCaN Network Roadmap

The SCaN Program has created a SCaN 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. The section also contains a brief overview discussion of security considerations.

3.1 Security Functions 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 functions 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. Further security details are found in SCaN ADD Vol. 2.

3.2 Phase 1 Evolution

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. These new standards will be developed during Phase 1 and implemented in Phases 1 and 2.

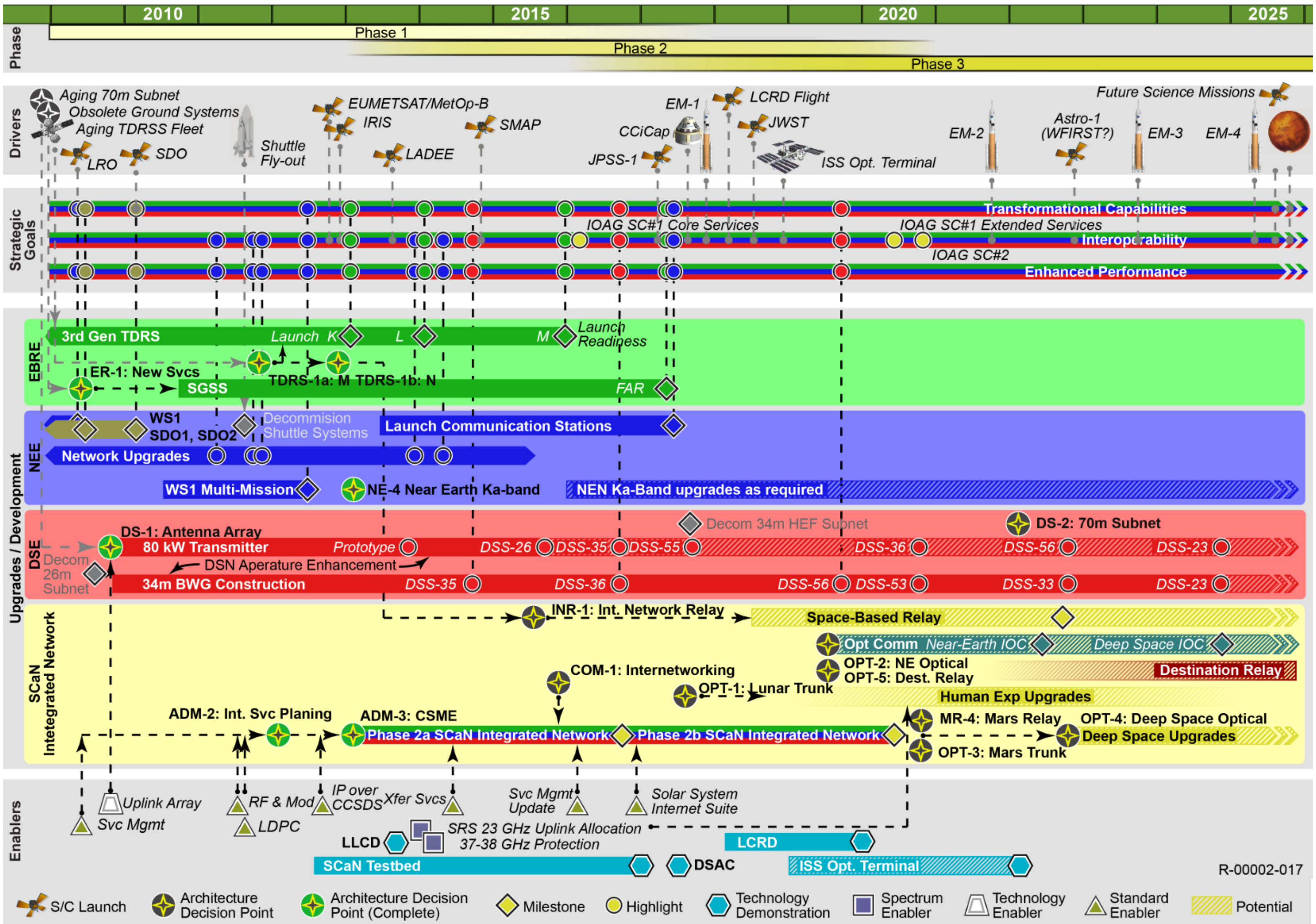

Figure 3-1. SCaN Network Roadmap

The first phase also includes significant increases in microwave data throughput, providing at least 1.2 Gbps in the near-Earth (LEO) 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.

3.3 Phase 2 Evolution

The deployment of the second phase of SCaN architecture evolution will integrate the three existing elements into one unified network. The second phase will enable increasingly sophisticated lunar science missions, and progressively more complex Mars and planetary science missions will also occur in this timeframe. The incremental implementation of Phase 2 capabilities overlaps with the end of Phase 1.

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

a) Additional antennas from the DAE Project in anticipation of the eventual retirement of the 70-m Subnet.

b) Space internetworking with DTN and IP employed by selected user missions

c) Integrated Network Management and Integrated Service

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. 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.

3.4 Phase 3 Evolution

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 near Earth and 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 human exploration, 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. Navigation improvements will include optimetric measurements with ranging at the centimeter level, including Doppler-equivalent observables. The deployment of space internetworking with DTN and IP across the SCaN architecture will provide seamless transitions between SCaN capabilities. Space internetworking with DTN and IP will be implemented throughout the solar system, with the SCaN Network providing the IP management infrastructure. Data confidentiality and uplink security will be implemented within the space internetwork. NASA will continue enhancements of the SCaN architecture and retirement of aging or obsolete microwave systems (such as the 70-m antennas) in this phase.

3.5 Architecture Decision Points

Table 3-1 lists the ADPs required to define the SCaN Architecture and their current status.

Table 3-1. ADP Descriptions

Year	Architecture Decision Point Descriptions	Status
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	**Complete:** Implement array of four 34-m Ka-band antennas per site; one 34-m antenna per site with 80kW transmitter; receive and transmit performance equivalent to 70-m
2009	**ER-1: New Earth Relay Services** – determine which new services should be included into the Earth Relay element, and when they should be provided	**Complete:** Decided not to implement augmented TDRSS position determination and on-demand Multiple-Access forward capabilities; Approved TDRS antenna arraying for increased performance by 2016
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	**Complete:** Constellation Program cancelled and SCaN implementation cancelled
2010	**ENT-1: Unified Service Pricing Approach** – establish an approach for unified service pricing, cost accounting, and attribution across the SCaN network.	**Cancelled:** Programmatic Decision not to fund study
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	**Cancelled:** SMD retained responsibility
2011	**LR-1: Coverage and Orbits of Lunar Relay Satellites** – determine the orbital configuration of the Lunar Relay Satellites and cislunar vicinity coverage based exploration missions requirements	**Cancelled:** Study was completed but Constellation Program was cancelled and no formal decision was made
2011	**TDRS-1a: Exercise TDRS M option** – determine whether to exercise the contract option to procure an additional third-generation TDRS	**Complete:** SCaN exercised the TDRS M option, but deferred launch until *2018*
2012	**NE-4: Near Earth Ka-Band** – determine how to implement Ka-band for near Earth Missions	**Complete:** Upgrade White Sands 1 (WS1) for multi-mission use, scar new antennas for Ka-Band, don't upgrade existing sites unless mission drivers emerge
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	**Cancelled:** SMD retained responsibility
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	**Cancelled:** Constellation Program was cancelled
2014	**OPT-1: Lunar Trunk Line: Optical or RF Ka-band Link –** decide if the lunar relay trunk should be implemented via	**Cancelled:** Constellation Program was cancelled and International

	optical or RF technology and define an optical IOC (if needed)	Lunar Network deferred
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	**Cancelled:** Constellation Program was cancelled
2013	**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	**Complete:** ADM-3 added CSME and allocated network integration and allocated network integration responsibility. Revised in ADM-3a splitting Phase 2 into Phases 2a and 2b to meet budget constraints.
2013	**TDRS-1b: Exercise TDRS N option** – determine whether to exercise the contract option to procure an additional third-generation TDRS	**3.5.1 Expired:** Contract option allowed to expire due to budget constraints
<u>2015</u>	**INR-1: Integrated Network Relay procurement** – decide the capabilities and schedule for the Earth-based relay capability that succeeds TDRSS	
<u>2015</u>	**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	
<u>2015</u>	**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	
2017	**OPT-1: Lunar Trunk Line: Optical or RF Ka-band Link –** decide if the lunar relay trunk should be implemented via optical or RF technology and define an optical IOC (if needed)	
2019	**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	
2019	**OPT-5: Destination Relay: Optical or RF Ka-band Link –** decide if the Destination Relay should be implemented via optical or RF technology and define an optical IOC (if needed)	
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	
2022	**DS-2: Deep Space 70-m Subnet Retirement** – determine if/when the 70-m subnet should be retired	

Section 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) Destination and Mars Relays
d) Integrated Network Management 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 program-level architecture (i.e., new capabilities, new & decommissioned facilities, major developments, and upgrade efforts). 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
ADM	Architecture Decision Memorandum
ADP	Architecture Decision Point
AMPM	Agency Mission Planning Manifest
AU	Astronomical Unit
BPGT	Blossom Point Ground Terminal
CCiCap	Commercial Crew integrated Capability
CCSDS	Consultative Committee for Space Data Systems
CLTU	Command Link Transmission Unit
ConOps	Concept of Operations
CR	Change Request
CSME	Customer Service Management Element
CSO	Communication Service Office
DAE	DSN Aperture Enhancement
Delta-DOR	Delta Differential One-Way Ranging
DCN	Documentation Change Notice
DESDynl	Deformation, Ecosystem Structure and Dynamics of Ice
DFE	Direct From Earth
DMSP&MO	DSN Mission Service Planning & Management Office
DSE	Deep Space Element
DSN	Deep Space Network
DTE	Direct To Earth
DTN	Disruption Tolerance Network(ing)
EBRE	Earth-Based Relay Element

Acronym	**Definition**
EM	Exploration Mission
EOP	Earth Orientation Parameters
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EVA	Extra Vehicular Activity
FAR	Final Acceptance Review
FDF	Flight Dynamics Facility
GEO	Geosynchronous Earth Orbit
GSFC	Goddard Space Flight Center
HEOMD	Human Exploration and Operations Mission Directorate
HST	Hubble Space Telescope
IEEE	Institute of Electrical and Electronic Engineers
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
IRIS	Interface Region Imaging Spectrograph
IOAG	Interagency Operations Advisory Group
IOC	Initial Operational Capability
IP	Internet Protocol
IPCE	Independent Program and Cost Evaluation Office
IRD	Interface Requirement Document
ISS	International Space Station
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JWST	James Webb Space Telescope
L2	Lagrange Point 2
LADEE	Lunar Atmosphere and Dust Environment Explorer
LCRD	Laser Communications Relay Demonstration
LCS	Launch Communications Stations

Acronym	Definition
LDPC	Low Density Parity Check
LEO	Low Earth Orbit
LLCD	Lunar Laser Communications Demonstration
LRO	Lunar Reconnaissance Orbiter
MAVEN	Mars Atmosphere and Volatile EvolutioN
MCO	Mission Commitment Office
MEO	Middle Earth Orbit
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MetOp-B	Meteorological Operational - B
MPCV	Multi-Purpose Crew Vehicle
MR	Mars Relay
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
NASA	National Aeronautics and Space Administration
NEE	Near Earth Element
NEN	Near Earth Network
NEO	Near Earth Object
NGIN	Next Generation Integrated Network
NIMO	Network Integration Management Office
NISN	Network Integrated Services Network
NPD	NASA Policy Directive
NPR	NASA Procedural Requirement
O&M	Operations & Maintenance
OCIO	Office of Chief Information Officer
ONE	Operational Network Element
PCA	Program Commitment Agreement
PMP	Program Management Plan

Acronym	Definition
RF	Radio Frequency
SAR	Synthetic Aperture Radar
SBR	Space-Based Relay
SCaN	Space Communications and Navigation
SCMM	Space Communication Mission Model
SDO	Solar Dynamics Orbiter
SDR	Software Defined Radio
SE&I	Systems Engineering & Integration
SEMP	System Engineering Management Plan
SGSS	SN Ground Segment Sustainment
SLS	Space Launch System
SMAP	Soil Moisture Active Passive
SMC	Strategic Management Council
SMD	Science Mission Directorate
SN	Space Network
SOHO	Solar and Heliospheric Observatory
SOMD	Space Operations Mission Directorate
SRD	System Requirements Document
SRS	Space Research Service
STEREO	Solar TErrestrial RElations Observatory
STS	Space Transportation System
SWOT	Surface Water Ocean Topology
TDRS	Tracking & Data Relay Satellite
TDRSS	Tracking & Data Relay Satellite System
TRL	Technical Readiness Level
TT&C	Tracking, Telemetry & Command
U.S.	United States

Acronym	Definition
WFIRST	Wide-Field Infrared Survey Telescope
WMAP	Wilkinson Microwave Anisotropy Probe
WS1	White Sands 1
WSC	White Sands Complex