Framework for NASA Space Relay Satellite Services over the Next Decade: Space Relay Partnership and Services Study

Eric Knoblock[1], Nang Pham[2], Joseph Downey[3], Phillip Paulsen[4], George Haddad[5], Michael Pepen[6], and Jon Drexler[7]*

[1,3,4]*Communications and Intelligent Systems Division, NASA Glenn Research Center, Cleveland, OH, USA*
[2]*Human Exploration and Space Operations Project Office, NASA Glenn Research Center, Cleveland, OH USA*
[5,6]*Systems Engineering and Architecture Division, NASA Glenn Research Center, Cleveland, OH, USA*
[7]*Cost and Economic Analysis Office, NASA Glenn Research Center, Cleveland, OH, USA*
**eric.j.knoblock@nasa.gov*

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Abstract

The United States National Space Policy provides guidance and directives for U.S. Government agencies to purchase commercial space services and capabilities to the maximum extent practical. In alignment with this guidance, the anticipated initial NASA near-Earth space relay operating capability over the next decade will be comprised of the existing NASA-owned Space Network infrastructure supplemented with commercially-owned and -provided relay satellites and their associated ground stations. NASA awarded contracts to eight study vendors in May 2019 to investigate the feasibility of applying commercial services concepts to the NASA user mission community. The studies, managed by NASA Glenn Research Center, detailed ten study topic areas. NASA completed the analysis and synthesis of these eight industry studies and other relevant information. The responses from the study vendors indicated a strong interest in providing commercial services to NASA missions, and included a wide range of proposed architectures and demonstration ideas. Overall, the responses indicated that a mature and healthy competitive environment exists across a broad spectrum of industry to deliver high-rate space relay services in the next three to five years. This paper will present an overview of the study, analysis and synthesis processes along with common themes and conclusions, and provide next steps and recommendations. The results of this study serve as a foundation for ongoing efforts to acquire interoperable space relay services for NASA missions from multiple commercial service providers.

1 Introduction

In the decades to come, the NASA Space Communications and Navigation (SCaN) Program will transform its architecture network model and will increasingly incorporate Commercial Satellite Communications (COMSATCOM) services. NASA's current and future near-Earth missions' needs could be met by the COMSATCOM capabilities and services as they expand their respective satellite and ground infrastructure. Incorporating COMSATCOM capabilities and services will help NASA in cost savings, scalability, capability resiliency, and further foster an affordable and robust commercialization in the United States.

Building upon prior studies [1][2][3], NASA pursued the Space Relay Partnership and Services study and awarded eight industry vendors out of seventeen (in 2019) for a total cost of approximately $4M under the Next Space Technologies for Exploration Partnerships-2 Omnibus Broad Agency Announcement (BAA) Appendix G [4]. The objectives of the BAA study are to assess commercial service concepts, accommodation of a NASA-provided optical payload, and the use of public-private partnerships for providing and receiving communication and navigation services. The selected vendors were: ATLAS Space Operations, Boeing, Eutelsat America Corporation, General Dynamics Mission Systems, Intelsat General Corporation, Maxar Space Solutions, Northrop Grumman, and SpaceX. All eight vendor studies were led and managed by NASA Glenn Research Center (GRC) with support from NASA Headquarters (HQ), the NASA Goddard Spaceflight Center (GSFC), the Jet Propulsion Laboratory (JPL) and NASA support contractors. Ten study topics were sought, specifically: 1) service provider interoperability, 2) user terminal interoperability, 3) service concepts of operations, 4) requirements review, 5) optical and RF commercial services, 6) accommodations of the NASA-provided optical payload, 7) secure data processing, 8) space internetworking, 9) business partnership and market viability, and 10) service transition plan. After the vendor contracts were awarded, NASA provided further guidance to emphasize on commercial RF capabilities and services, and to consider operational optical services after the successful of the NASA Laser Communications Relay Demonstration (LCRD).

In order to further focus, analyze, and manage the vast amount of data and information from the eight vendor studies, the 10 topics were stratified into four key study areas and each team of expertise from the aforementioned NASA Centers and its contractors were assigned to assess each key area. Overall integration of the information and results from

all the study areas was accomplished by the study area leads and the project manager. The four key areas are systems engineering, communications capabilities, interoperability & data, and business public-private partnership.

NASA completed the analysis and synthesis of these eight industry studies and other relevant information. The results and recommendations from this study provide a framework for NASA to implement interoperable space relay services from multiple commercial service providers in the decades to come. This paper will present an overview of the study, analysis and synthesis processes along with common themes and conclusions, and provide next steps and recommendations.

2 Assessment and Analysis

As mentioned, NASA completed the analysis and synthesis of these eight industry studies and other relevant information in the key areas of systems engineering, communications capabilities, interoperability & data, and business public-private partnership. The following sections provide an overview of this assessment and analysis.

2.1 Spectrum Challenges

Many COMSATCOM service providers use the Fixed Satellite Services (FSS) or Mobile Satellite Services (MSS) allocations for users that reside primarily in the terrestrial and airborne domains [5]. Most BAA study vendors highlighted that International Telecommunications Union (ITU) regulations prohibit such allocations to be used for space-to-space communications (i.e., space relay to space-based user), which poses a challenge for NASA user missions that typically operate at LEO distances and beyond. According to the ITU regulations, any space-based system that attempts to use the FSS or MSS allocations for space-to-space communications must operate in a non-interfering basis and are thereby prohibited from either causing or accepting any RF interference from appropriately licensed users.

Several of the BAA study vendors recommended that NASA work jointly with industry to suggest changes to the ITU regulations for FSS and MSS allocations. Accordingly, in August 2019, the U.S. proposed an agenda item for the 2023 ITU World Radiocommunication Conference (WRC-23) specifically to investigate the use of space-to-space communications within MSS and FSS frequency bands. The suggested agenda item was accepted for WRC-23, and in preparation, NASA plans to reach out proactively to U.S. regulators and industry to work towards solutions that are mutually beneficial to government and commercial interests. Alternatives to using FSS and MSS allocations include direct-to-Earth services (ranging from 137 MHz to 84 GHz) and services operating under Inter-Satellite Services (ISS) allocations (ranging from 2 to 71 GHz).

In addition to regulatory changes, the study vendors offered various other suggestions, such as conducting interference mitigation studies to identify strategies for concurrent usage of ISS and FSS bands. Other options proposed modifying antenna technologies, such as electronically steerable arrays, to include both FSS and ISS spectrum accommodations (a potentially expensive option), or including separate ISS radio frequency (RF) hardware on the spacecraft.

2.2 Interoperability

Achieving interoperability among U.S. Government, commercial, or international space agency partners would potentially allow for NASA user missions to "roam" or transition among service providers. Obtaining services from multiple, independent providers facilitates commercial competition and alleviates NASA's dependency on any single provider. This allows for ensured service continuity and mitigates the risk of cost increases, service prioritization issues, and any other factors affecting the providers' ability to meet their service commitments. As part of the study guidance, the BAA study vendors were asked to evaluate what would be required to achieve NASA's vision of interoperability, and the responses are summarized as follows. Supplemental interoperability information is provided in reference [6].

2.2.2 Various Perspectives on Interoperability

The study vendors offered various perspectives on achieving NASA's desired vision of interoperability. Some suggested that interoperability is imperative in the commercial market, and that is a common practice among FSS providers (or "competi-mates") to exchange bandwidth via common proprietary modems across different services.

Others noted that interoperability is not required for many COMSATCOM applications. This contrasts with the cell phone industry that achieved the desired roaming concept; however, the primary driver for interoperability between providers' cell phones and cellular towers was the desire for enhanced cellular coverage area. For coverage of a large area, such as the U.S., each cellular service provider had an incentive to work with other providers to share usage of systems. In the satellite domain, however, global coverage may be achieved with only three operational GEO spacecraft, for example, thereby eliminating the need for interoperability if one provider is willing to invest in the deployment of those orbiting assets.

In some cases, COMSATCOM providers may offer unique services, such as steerable spot beams. In this case, there is no competition and therefore no incentive to strive towards interoperability with other providers.

2.2.2 Interoperability Standards

NASA's envisioned pathway to achieving interoperability among providers comes through various efforts, one of which relates to standards development. Accordingly, the BAA study vendors offered suggestions relating to standards to achieve interoperability, as described in the following paragraphs.

In the case of optical communications standards, BAA responses noted that the first vendor that can mass-produce

affordable terminals at scale will likely influence the market, and suggested that NASA takes a lead in the development of appropriate interfaces and standards (with industry cooperation). Space-based optical communications standards are currently pursuing two different wavelength variants. One variant pursued in Europe uses the 1064 nm wavelength; the other variant that is being pursued by the U.S. and Japan is the 1550 nm wavelength [7]. NASA serves as the chair for the CCSDS Optical Communications Working Group, and standards for both optical wavelengths are currently under development.

Vendors noted that, in general, standards alone do not fully allow for interoperability among systems. The standards specifications provide a set of underlying guidelines (or "building blocks") upon which the detailed interfaces between components can be specified, typically within either an Interface Requirements Document (IRD) or Interface Control Document (ICD). In the case of optical communications, for example, the responses noted that many specifications (such as pointing, acquisition and tracking, for example) are not included within the CCSDS guidelines, and therefore must be contained within a companion IRD/ICD to complete the interface. BAA study vendors also recommended the use of interoperability profiles as a method to specify the missing requirements needed to define the interface.

2.2.3 Impacts on Business Case

In addition to the technical challenges, achieving the space-roaming concept poses impacts to the service providers' business cases, and consequently affects their ability to maintain viability in the commercial services market. From the vendor perspective, developing a system that enables interoperability reduces the barrier-to-entry for competitors, thereby compromising any market share captured by the initial vendor. When pursuing public-private partnerships, NASA may need to assume additional financial burden to offset the vendors' resultant market risk due to competition. This is especially true in the case of the nascent optical communications market, which at this point, consists of limited commercial providers, terminal developers, and flight users. While the concept of multiple interoperable providers may allow NASA to benefit from additional redundancy and avoidance of provider lock-in, any decrease in service costs due to competition will have an adverse effect on the vendors' market share, and may require greater financial contributions from NASA to enable a viable partnership with industry.

2.3 User Terminals

Due to the considerable investment in developing commercial SATCOM services and infrastructure, the consensus among vendors was to address interoperability at the user terminal level versus modifying or changing the relay satellites or services. Several vendors recommended the development of multi-waveform, multi-frequency user terminals as an approach for achieving interoperability between multiple services. Interoperability with commercial satellite communication service providers will require space-qualified user terminals with the capability to roam among multiple RF or optical services, while being competitive with single-provider user terminals with regards to mass, power, volume and cost. While such an interoperable terminal will have additional design challenges due to Size, Weight and Power (SWaP) constraints, the use of software-defined modem technology will allow multiple waveforms to be hosted on a common hardware platform, providing considerable savings over accommodating separate user terminals for each service. Accommodating multiple proprietary waveforms was identified as a challenge, as well as addressing user authentication and security considerations. Furthermore, in order to be compatible with a wide range of service providers, the RF front end, antenna, and frequency converters must operate over multiple frequency ranges (i.e., "wideband").

Regarding current space-qualified user terminals for commercial services, only a few solutions are currently available, including low-rate L-band services [8]. While several Ka-band user terminals exist for NASA's Tracking Data and Relay Satellite System (TDRSS) and the European Space Agency (ESA)'s European Data Relay Satellite System (EDRS), no commercially off the shelf terminals exist for commercial Ka-band services. Consistent with the BAA study recommendations, NASA has already begun the development of wideband Ka-band user terminals to address this gap.

2.4 Optical Payload Accommodations

As part of the BAA study guidance, the vendors were asked to evaluate the integration and accommodation of a NASA-provided optical communication payload onto the partner relay satellite. In contrast to a hosted payload service, the requested accommodations and terminals may provide optical services to NASA missions as well as other commercial missions. This scope of the study also included conducting any necessary trades for shared spacecraft resources or functions (e.g., power, mass, volume, data, stability/pointing, field of regard, thermal, and other interfaces). This section provides an overview of the responses from the study vendors.

As part of this study, the vendors evaluated the ability to accommodate the optical payload based on various criteria, some of which included: volume/mass, electrical interfaces, thermal considerations, launch vehicle compatibility, platform stability, and others. Based on the evaluations, the overall consensus was that many medium-sized spacecraft buses (~5000 to 6000 kg launch mass) can reasonably accommodate the optical payload. A limited smaller-sized spacecraft platform (~2000 kg launch mass) may also accommodate the optical payload. The vendors also noted that the specific bus selection would be driven by final optical payload capability and accommodation requirements and would require a viable business case.

Since optical communications is a relatively nascent technology, the NASA optical communications payload has a projected lifetime of 5 to 8 years to allow for necessary

technology refresh. However, many of the study vendors noted that the typical mission lifetime of the GEO satellites used within their fleets is around 15 years, and that increasing the lifetime of the NASA optical payload would provide for a more attractive business case to commercial partners.

In order to allow for contingency communications in the event the optical link is obstructed by cloud cover or other impediments, the NASA payload accommodations specification calls for access to and usage of a high-rate Ka-band RF link on the partner spacecraft. Accordingly, the vendors evaluated the options of either an RF system integrated with the optical payload or a stand-alone (i.e., dedicated) RF payload. In general, the vendors noted that dedicated RF payload solutions are limited due to 1) antenna size and real estate restrictions and 2) RF bandwidth availability. Alternatively, an RF payload integrated with the optical system may allow for reduced integration non-recurring engineering (NRE). Further, the integrated functionality may support contingency links with reduced burden on the host spacecraft.

2.5 Service Transition Plan

The BAA vendor studies found many avenues for transition from NASA-owned and -operated to leveraging commercial industry capabilities to the greatest extent possible. To that end, the team found that NASA should pursue maintaining the TDRSS fleet until end of life and in parallel pursue commercial services for communication with spacecraft in near-Earth orbit. To develop these novel services NASA could establish partnerships with multiple commercial satellite communications companies to develop and demonstrate capabilities that can meet NASA's needs. The capabilities demonstrated should explore new spectrums (optical, Commercial RF, etc.) to expand the services NASA missions can utilize.

The demonstrations areas could focus on the following:

- Demonstrate highly reliable low rate communication services to deliver telemetry and command data
- Demonstrate reliable high data rate communication services to transmit data
- Demonstrate new evolutionary communication capabilities not traditionally leveraged by NASA. This could include hybrid approaches that could utilize Direct-To-Earth (DTE), Relay, or Cloud Computing capabilities.

Once the demonstration phase is completed, NASA could select services to offer to missions, in a similar fashion to how commercial Launch has succeeded in enabling commercial services.

2.6 Business Partnerships and Market Viability

In general, the BAA responses indicate strong interest in providing commercial services. The studies span a wide range of architectures and demonstration ideas. The responses indicate a mature, healthy competitive environment from a broad spectrum of industry to deliver high-rate space relay services in the next three to five years.

NASA's long-term goal is to be one of many customers for commercial services. The results identified potential markets and non-NASA customers that could help reduce NASA's share of capital expenses and ensure competitive market-based pricing of services. Commercial development of several initiatives has been initiated by several vendors and some commercial services are even available today. However, demonstrations will be a key part of this process and the studies shared a wide range of demonstration ideas. The agency is using this information in planning its next steps.

NASA is strongly considering using a Public Private Partnership (PPP) approach with performance-based fixed-price milestones, which are paid only after demonstrating pre-defined objectives. The responses provide the agency with some of the market survey information needed to proceed with PPP acquisition planning. However, the studies show that there are many variables that need to be segregated and prioritized as NASA refines this strategy. In general, the results suggest that NASA should consider a multi-phase, incremental approach to meeting its long-term objectives.

3 Common Themes, Trends, and Conclusions

Three common themes were identified from the vendor studies. The first theme is ensuring NASA as one of many customers; second theme concerns the business public-private partnerships; and the last theme is a collection of interoperability, security, spectrum and exchange. With these themes, the trends and conclusions are summarized.

3.1 Ensuring NASA as One of Many Customers

NASA is encouraged to demonstrate and start using existing commercial RF services. The study vendors anticipate competition in the RF market to grow as space data relay services, particularly for NASA and government users, become a proven source of commercial revenue.

The study vendors identified potential markets and non-NASA customers that could help reduce NASA's share of capital expenses and ensure competitive market-based pricing of services. The likely early adopters might be from the Department of Defense (DoD) and foreign governments. Other potential customers include other government agencies, airlines, and cruise lines. Commercial development of several initiatives has been initiated by several vendors and with the right investment, NASA could fit into these approaches.

Most of the study vendors identify NASA investment as a key enabler (i.e., anchor tenant).

When assessing a potential partnership approach, NASA needs to ensure that any investment to enable a commercial solution must also align to a market with non-NASA customers.

3.2 Business Public-Private Partnerships (PPP)

As mentioned, the BAA responses indicate strong interest in providing commercial services with a wide range of potential architectures and demonstration ideas. The responses indicate a mature, healthy competitive environment across industry to deliver high-rate space relay services in the near term.

Several companies have the existing ability to sell RF services today that may meet some of NASA's needs without the need for a public-private partnership. Overall, study participants see existing commercial services as having potential to meet NASA space data relay needs, but their capabilities must be verified. As a result, capability demonstrations are a necessary first.

Most study vendors did not provide key elements of a viable business plan to develop and demonstrate the enhanced communications services. Several cited the need for NASA to identify the expected long-term funding commitments for the purchase of services in order to quantify the business case and investment internal rates of return. Thus, there was very limited insight into NASA's share of PPP development costs as well as projected pricing necessary to inform NASA's acquisition planning and budgeting.

NASA's vision for space relay services is complex with many variables. Additional work is needed to clearly identify the minimum essential requirements, expected transition timeframe, and funding commitments to stimulate the development and demonstration of new commercial capabilities and phase-in of services.

The BAA study responses have informed some of the market survey information needed to proceed with PPP acquisition planning. There are many variables that need to be segregated and prioritized such as RF, optical, payload, LEO, Cis-lunar, deep space, relays, ground segment, interoperability, etc. NASA should consider a multi-phase, incremental approach to meeting its long-term objectives.

3.3 Interoperability/Security/Spectrum/Exchange

For NASA to use proposed commercial services, there is a need to develop and demonstrate user space RF terminals which are interoperable with multiple commercial networks.

Companies suggest NASA to monitor and leverage the results of current efforts for developing interoperable ground terminals for interoperable space terminals. The current efforts include Flexible Modem Interface (FMI) study and commercial ground terminal providers have successfully demonstrated connections to multiple commercial satellites through a single terminal.

A majority of the companies mentioned RF commercial spectrum availability issues. Companies suggest an option to explore amending the rules to allow Inter Satellite Service (ISS) to be performed with Fixed Satellite Service (FSS) spectrum bands. Also, access to government spectrum is desired.

All companies discussed compliance with existing terrestrial cyber standards. Several companies offer enhanced security (such as Multi-Level Security (MLS) for hosted payloads) as an additional service.

Several companies proposed leveraging foreign-owned communications networks. NASA will need to assess the associated eligibility, policies, and risks of these offerings.

Multiple companies proposed some form of COMSATCOM exchange or enterprise multi-network management system establishing a "one-stop shop" for a range of COMSATCOM solutions.

4 Recommendations and Next Steps

Based on the breadth, depth, and complexity of the existing SCaN user market and services required, coupled with the BAA study results, it is obvious that "one size cannot fit all". Instead, a collection of technologies and COMSATCOM services will need to be further defined, developed, qualified, and proven in space.

In order to accomplish this, a series of logical, orderly steps, leading to COMSATCOM service development and flight, are recommended to the NASA SCaN Program:

- Continue to engage with the Mission User community to capture future near-Earth mission user needs. This assessment will evaluate such things as: use of a relay vs direct-to-ground spacecraft communications services, definition of low/high/ultra-high data rates & volumes, data latency requirements, timing requirements, tracking, ranging & navigation services, launch vehicle support, LEOP/TOSS support, end-to-end security support, contingency support, etc. In addition, prioritizing, scoping and phasing of the integrated mission needs will also need to be conducted.

- Continue to interact with the commercial communication service providers and to assess their COMSATCOM capability and capacity to provide services for NASA flight missions. This assessment also needs to include the identification of any technology or service development necessary for the mission users to be able to take advantage of the new services.

- Develop a transition plan considering a multi-phase, incremental approach to meeting the long-term objectives. Given the complexity of the task, it is reasonable to assume that it will need to be conducted in multiple, interrelated, phases:

  - Phase 1: Demonstrate individual capabilities (2020 until 2022)
  - Phase 2: Demonstrate end-to-end services (2022 to 2025)
  - Phase 3: Enterprise service management (beyond 2025)

- Work with COMSATCOM service providers to define and develop a commercial communication services framework to enable user mission services provision (e.g., a published Service Catalog, User Guides, Service Level Agreements, etc.).

- Continue to collaborate with the DoD and other government agencies (OGAs) to share information, plans, studies, reports, technology, and other materials relating to topics of mutual interest. Mutual interest includes but not limited to:
  - Flexible terminals for users in order to utilize the services of multiple commercial providers.
  - A mechanism for managing SATCOM capacity from multiple commercial providers.
  - Interest in the resilience of the SATCOM architecture supporting their users.
  - Effective management of federal spectrum will be a shared interest across the whole government.

- Initiate the development of commercially available, flexible user spacecraft terminals capable of supporting multi-waveform / multi-frequency communications in order to be able to utilize the services of multiple commercial providers to ensure service resilience and mitigate risk of vendor lock.

- U.S. Government assistance with obtaining RF spectrum access for commercial space-to-space links.

- Develop and conduct early space relay partnership pathfinder risk reduction demonstrations – RF, optical, or both. Also modify existing NASA ConOps to facilitate transition to use of commercial services.

- Address standards and interoperability from industry point of view.
  - Support creation of standards which can be used by any commercial service provider to ensure interoperability (e.g., commercial development of open source hardware, software, service and interoperability standards)
  - Encourage industry to create a consortium to address space-to-space link connectivity and services and other common concerns (e.g., commercial development of an open standards-based service portal to field mission user service requests, poll potential COMSATCOM service providers, generate a rolling, user responsive service schedule, effect that schedule, and collect, analyse, and display heuristic data to provide integrated system situational awareness).
  - Provide support for standardized optical terminal development.

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