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Interoperability and Concepts of Operation Assessment for Space Relay Services and Partnerships

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Abstract

NASA is exploring potential partnerships with industry to leverage commercial space communication and navigation infrastructure to provide services to NASA user missions in the near term, which is expected to yield substantial development and operations cost savings. Recently, NASA awarded contracts to eight study vendors to investigate the feasibility of applying commercial services concepts to the NASA user mission community. The vendor studies were managed by NASA Glenn Research Center, and the study guidance detailed ten topic areas. This report provides a summary of the significant and nonproprietary findings and recommendations relating to three of the ten topics areas, specifically: service provider interoperability, user terminal interoperability, and commercial services concepts of operations. The results of this effort will inform the recently established Communications Services Program, which is further investigating the use of commercial satellite communication services for future NASA missions operating in low-Earth orbit and beyond.

1.0 Introduction

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 (Ref. 1). In alignment with this guidance, NASA is exploring potential industry partnerships to leverage current or planned commercial space communication and navigation infrastructure to provide services to NASA user missions in the mid-2020s. Leveraging commercial infrastructure and reducing NASA's reliance on government-owned and operated infrastructure should yield substantial development and operations cost savings. Additionally, the commercial services market will offer NASA a variety of service offerings at competitive prices, while simultaneously allowing NASA to benefit from commercial best practices (Ref. 2).

Under Appendix G of the Next Space Technologies for Exploration Partnerships (NextSTEP-2) Broad Agency Announcement (BAA), 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 vendor studies, managed by NASA Glenn Research Center, were completed in October 2019 and detailed ten study topic areas, three of which included: service provider interoperability, user terminal interoperability, and commercial services concept of operations. This report provides a summary of the significant (nonproprietary) findings and recommendations relating to those study areas from the BAA study vendors.

Within the topic of interoperability, NASA is seeking an approach for internetworked compatibility among multiple service providers (e.g., commercial, U.S. Government, or other international space agency partners), which would enable NASA user missions to "roam" or transition operations among providers. Achieving interoperability includes technical accommodations from both the service providers and the corresponding user flight terminals, and possibly include any required technical and financial contributions through partnerships with NASA. To ensure a competitive market with fair pricing and quality services, at least two commercial providers should exist and offer services. The topic of interoperability also includes an assessment of the technical functionality of the user terminal required to enable the capability to roam among multiple service providers. The user terminals must also remain competitive with single-provider terminals in terms of mass, power, volume, and cost, to the greatest extent possible.

This service concept of operations includes the description and trades associated with service management (e.g., service planning, scheduling, accounting, and user prioritization), and service execution and operations (e.g., link acquisition, authentication, QoS, and data delivery). The study also covers concepts relating to the enterprise management approach including the integrated hybrid system of heterogeneous assets (both government and commercial) working in conjunction to facilitate a service offering to NASA missions that are within the broader portfolio of overall commercial service offerings.

2.0 Interoperability

NASA is exploring potential partnerships with industry to leverage and acquire commercial space communication and navigation (C&N) services for NASA user missions beginning in the mid-2020s timeframe. The transition to commercial C&N services may provide for increased development and operations cost savings as compared to managing government-owned and operated communications infrastructure. The commercial services market also allows for a more diverse suite of commercial services options while simultaneously allowing NASA to benefit from commercial best practices.

This report provides an assessment of technical and business considerations that must be addressed in order to achieve interoperability among U.S. Government, commercial, or international space agency partners, allowing 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. At a minimum, two or more commercial providers should exist to ensure a competitive market with multiple service options.

2.1 Pathway to Interoperability

NASA’s envisioned pathway to achieving interoperability among providers comes through efforts relating to 1) standards development, 2) spectrum and regulatory activities, and 3) technology development. NASA supports standards development by participating in international standards bodies such as the Consultative Committee for Space Data Systems (CCSDS), and by supporting the adoption of commercial standards whenever appropriate (Ref. 3). In some cases, the development of new standards is necessary, such as in the domains of optical communications, enterprise network management, and Disruption Tolerant Networking (DTN) (Ref. 4). Spectrum and regulatory efforts focus on identification of spectrum needs for the growing space communications market, and the removal of regulatory barriers that impede progress of achieving international interoperability. Technology efforts strive to anticipate the communications and navigation needs of future missions, and focus on investment in high-impact technologies that, once infused, can offer the desired capabilities. Technology enablers for interoperability include wide-bandwidth Ka-band receivers that can operate across all Ka-band spectrum (commercial, military, and government allocations), and the investment in cognitive communications networks, which offer the advantage of dynamic, flexible user access with improved security and resiliency. Other technology enablers, such as the Flexible Modem Interface (FMI) and software-defined modems, are candidates as well.

As commercial SATCOM providers are not inherently interoperable, achieving the desired roaming capability requires technical modifications to both the service provider networks and the user flight terminals, potentially placing enhanced burden on NASA infrastructure and user spacecraft to ensure compatibility. Additionally, each commercial partner will require a profitable business case to justify the desired result, which may entail either a minimum level of service commitment from NASA or an anchor customer agreement in order to achieve a viable partnership. The following sections elaborate on the technical and business case aspects of achieving interoperability among service providers.

2.1.1 Spectrum and Regulatory

Many commercial service providers use the Fixed Satellite Services (FSS) or Mobile Satellite Services (MSS) allocations for users primarily in the terrestrial/airborne domain. However, 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 the NASA user community operating at LEO distances and beyond. According to the regulations, any space-based system that attempts to use the FSS or MSS allocations for space-to-space communications must operate in a noninterfering basis, prohibited from either causing or accepting any RF interference from appropriately licensed users.

NASA is investigating the potential use of FSS/MSS allocations for data relay services, and several of the BAA study vendors recommended that NASA 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 (Ref. 5). 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).

2.1.2 Standards

The goal of standardization is to enhance interoperability and cross-support among participating partner entities, while also reducing cost, risk, and development time. Standardization also facilitates the sharing of assets (e.g., ground stations or relay satellites) among the various partner agencies for enhanced operational capabilities and for sharing of infrastructure usage costs. In the case of optical communications, for example, cloud blockage is a significant challenge affecting space-to-ground communications, and therefore the ability to use multiple geographically diverse ground stations via cross-support with partner agencies allows for improved communications availability. NASA participates in various international standards committees, including the CCSDS, the Internet Engineering Task Force (IETF) (Ref. 6), and any others that support development of open and interoperable standards.

2.1.2.1 CCSDS and IOAG

The CCSDS is a multinational organization focusing on the development of open communications and data standards for space systems, with the goal of enhanced interoperability and cross-support, with a simultaneous reduction in mission risk, development time, and project costs. NASA participates in and chairs many of the CCSDS working groups.

In the case of optical communications, 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 by Tesat-Spacecom in Europe operates using the 1064 nm wavelength; the other variant that is being pursued by the U.S. and Japan is the 1550 nm wavelength. NASA serves as the chair for the CCSDS Optical Communications Working Group, and standards for both optical wavelengths are currently under development.

In coordination with the CCSDS, the Interagency Operations Advisory Group (IOAG) works to enable cross support among international partner agencies, including NASA, the Japan Aerospace Exploration Agency (JAXA), ESA, the National Centre for Space Studies (CNES), the German Aerospace Center (DLR), and others. The IOAG, established in 1999, meets regularly throughout the year with the goal of providing a forum to identify common needs across multiple international agencies for matters related to interoperability and space communications (Ref. 7).

2.1.2.2 Commercial Standards

In addition to CCSDS, NASA is amenable to working with other commercial standards organizations, provided the standards are open and internationally viable for a diverse set of service providers. BAA responses suggested that NASA support the creation of commercial standards that can be used by any service provider to ensure interoperability. Further, the vendors suggested that NASA reach out to industry to encourage the creation of a consortium to address space-to-space link connectivity and services and other common concerns.

2.1.2.3 Interface Control Specifications

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, BAA 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.

While the nature of space communications (e.g., long communications link distances) may necessitate unique solutions in some instances, from a commercial perspective, limiting the number of ICD variations can reduce system complexity and cost, which allows for a reduced cost of entry and enhanced market growth. Complexity is a significant factor relating to scalability, and poor scalability can limit the commercial growth that NASA needs to make space missions routine and affordable.

2.1.3 Technologies

As NASA future mission plans continue to evolve, new technologies and capabilities will be introduced into the space communications architecture to accommodate the anticipated mission needs. NASA technology efforts focus on the investment in low-maturity (in terms of Technology Readiness Level) and high-impact technologies that enable the envisioned capabilities. The envisioned future architecture with new enabling technologies will provide services to user missions communicating over diverse network provider elements, including relay and surface assets throughout the solar system (Ref. 8).

As a challenge to interoperability, BAA responses noted that commercial service providers typically operate over wide frequency ranges with little standardization regarding center frequencies and allocated bandwidth. Additionally, most providers implement proprietary waveforms with custom authentication and security measures that may require specific configurations of the user flight terminal prior to launch. As a result, enabling NASA user missions to roam among providers would require a user flight terminal with the ability to operate over wide frequency ranges and include provisions for accommodating multiple proprietary waveforms. These factors also affect the terminal's size, weight, and power (SWaP) considerations.

NASA is exploring various technologies to overcome those technical hurdles, including 1) wideband receivers that allow for operation across all Ka-band spectrum (both government and commercial), 2) software-defined modems that can implement multiple proprietary waveforms, and 3) cognitive networks that provide for dynamic, flexible user access with increased security and resiliency. The following sections provide further description for these technologies and others.

2.1.3.1 Wideband Ka-Band Receiver

The user-roaming concept requires that user platforms have the ability to connect to various provider networks (both government and commercial) depending on mission needs. Since the Ka-band spectrum spans several gigahertz covering allocations for government, military, and commercial users, there is a need for frequency-flexible hardware that can to tune to the various frequency bands. NASA technology programs are working on the development of a wide-bandwidth Ka-band radio system. The system will use software-defined radios capable of storing and running multiple waveforms.

2.1.3.2 Cognitive Networks

The cognitive communications and networking efforts at NASA strive to develop cognitive capabilities for increased mission science return, improved resource efficiencies, and increased autonomy and reliability of the NASA's next generation communications architecture through incorporation of machine learning, artificial intelligence, and other strategies. In order to achieve this enhanced set of capabilities, NASA researchers are striving to implement a "space cloud" concept, derived from the cloud computing paradigm, to achieve a service-oriented architecture with distributed cognition, de-centralized routing, and shared, on-orbit data processing. NASA believes that cognitive networks will facilitate more dynamic and flexible user access to provider networks with an increase in security and resiliency (Ref. 9).

2.1.3.3 Flexible Modem Interface (FMI)

The U.S. Department of Defense launched a pilot program to investigate flexible communications terminals that may operate across multiple provider networks, over diverse frequency bands, and with support for multiple disparate waveforms and modems. The Flexible Modem Interface is a control plane interface standard that enables terminal flexibility and is considered an important step in joining disparate terminal segment capabilities for various provider networks and services. FMI consists of multiple components, including a wideband antenna and RF front end, multiple proprietary modems, and a terminal controller that manages the terminal operations. Multiple BAA study vendors suggested that NASA investigate leveraging the FMI concept as part of its desire to achieve the ability to roam among multiple service providers (Refs. 10 and 11).

2.1.3.4 Software Defined Modems

As the name implies, software-defined modems use reconfigurable software in place of hardware to implement modulation and demodulation functionality. Incorporating multiple proprietary waveforms within a single unit may allow for the desired interoperability and roaming among providers assuming that the provider networks are willing to share their proprietary waveforms and protocols. Switching between provider networks would require a software-based mechanism to evoke the appropriate waveform based on the desired network, and a wideband front end would be necessary to span the providers' frequency ranges.

Viasat Inc., in late 2019, developed the first-ever software-defined modem authorized to operate on the Wideband Global Satellite (WGS) communications network. The Viasat CBM-400 allows the flexibility to switch over to new satellite networks in near real-time in order to meet the needs of nearly any mission and application (Ref. 12).

2.2 Barriers to Interoperability

BAA responses indicated a strong interest in providing commercial services with a wide range of proposed architectures and demonstration concepts; further, the study responses indicated that there is a mature, healthy competitive environment across industry for high-rate space relay services in the next three to five years. However, achieving the ability for NASA missions to roam seamlessly from one service provider to another comes with several technical and business challenges, as described in the following sections.

2.2.1 Technical Challenges

As mentioned, commercial service providers are not inherently interoperable, as each provider seeks to maintain its competitive advantage and market share with unique interfaces and proprietary mechanisms for provision of user services. Differences among providers span multiple protocol layers, software implementations, and operational processes including, for example, unique scheduling and service negotiating processes, proprietary RF and optical waveforms and modems, proprietary network parameters for security and access control, unique acquisition and pointing approaches, and unique service accountability and reporting mechanisms.

Overall, the BAA study vendors viewed existing commercial SATCOM services as having the potential to meet NASA's space data relay needs, but recommended a series of time-phased incremental capability demonstrations as an avenue to overcome the technical hurdles and achieve the desired end state. In additional to conducting capability demonstrations, NASA's approach to overcoming these technical hurdles is through standards development, spectrum and regulatory activities, and technology development, as was described in detail in the preceding sections.

2.2.2 Business Case Impacts

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 (Ref. 13), 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.

The cell phone industry 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 service provider had an incentive to work with other providers to share usage of systems. In the satellite domain, however, global coverage can be achieved with only three operational GEO spacecraft, for example, which eliminates the need for interoperability if one provider is willing to invest in the deployment of those orbiting assets.

As a result, encouraging commercial satellite communications providers to seek for interoperability among its competitors would require a strong business incentive to offset the reduced market share and decreased service costs due to competition. In fact, several BAA vendors 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. When assessing potential partnership approaches, NASA should insure that any investment to enable a commercial solution must also align to a market with non-NASA users.

2.3 Interoperability Summary

NASA's envisioned pathway to achieving interoperability among providers comes through standards development, spectrum and regulatory efforts, and technology development. BAA responses provided several suggestions for NASA to consider when transitioning to future partnerships with industry. However, commercial service providers are not inherently interoperable, as each provider seeks to maintain its competitive advantage and market share through unique interfaces, processes, and proprietary implementations. Consequently, achieving an interoperable commercial space communications infrastructure would require efforts to overcome the technical hurdles while addressing the business case challenges associated with partnerships with industry.

3.0 Concepts of Operation

As defined within the BAA guidelines, NASA is interested in a service concept of operations that addresses service management, service operations (e.g., scheduling, link acquisition, authentication, and accounting), the enterprise architecture, and other related service aspects. The BAA study vendors brought forth various concepts for space relay services, and the following sections provide an overview of the proposed concepts of operations.

3.1 Service Architecture

The service architecture for the various commercial providers consists of similar architecture components, including:

- Spacecraft Operations Center (SOC): a facility that manages, controls, and monitors all aspects of the relay spacecraft fleet. Activities include station-keeping maneuvers, monitoring of fleet state-of-health, and responding to any detected anomalies.
- Network Operations Center (NOC): a facility that serves as the primary interface with the user mission ground systems for service planning, scheduling, and monitoring activities. The NOC provides directives to the SOC for service setup commands, and receives user platform and spacecraft status messages from the SOC before, during, and after service provisioning.
- Relay Spacecraft: fleet of spacecraft that provide communications relaying capabilities from user mission platforms to ground stations on the earth. Relay spacecraft can be in various orbits, such as LEO, MEO, or GEO.
- Ground Stations: RF or optical stations on the earth that provide uplink and downlink connectivity to relay spacecraft in space.
- Meet-Me Rooms: facilities that allow multiple internet service providers or telecommunications carriers to converge and interconnect for the exchange of data over terrestrial fiber optic links.
- User Mission Ground System: The ground systems providing mission planning, scheduling, commanding, data processing, etc., for the user missions.
- User Mission Platform: The user mission system that is communicating (via RF or optical links) with the provider’s relay network.

Figure 1 illustrates the service architecture. As shown, user mission personnel on the ground interface with the service provider’s Network Operations Center for service planning and scheduling activities. The Spacecraft Operations Center monitors and controls the relay spacecraft fleet, and the user mission platforms in space transmit data through the relay spacecraft to the ground via RF or optical links. Once on the ground, the user mission data is processed and then forwarded to the user mission ground personnel over high-rate terrestrial links.

Not shown in the figure, several BAA study vendors proposed a form of an enterprise multinetwork management system or “one-stop shop” for users to acquire a range of commercial satellite communications solutions. The proposed concept would relieve user burden in terms of service planning, and would facilitate the capability of obtaining services from multiple provider networks.

3.2 Service Management

Service management includes processes relating to the planning, scheduling, and reporting of the space communications services provided to the user missions. The following sections describe these processes.

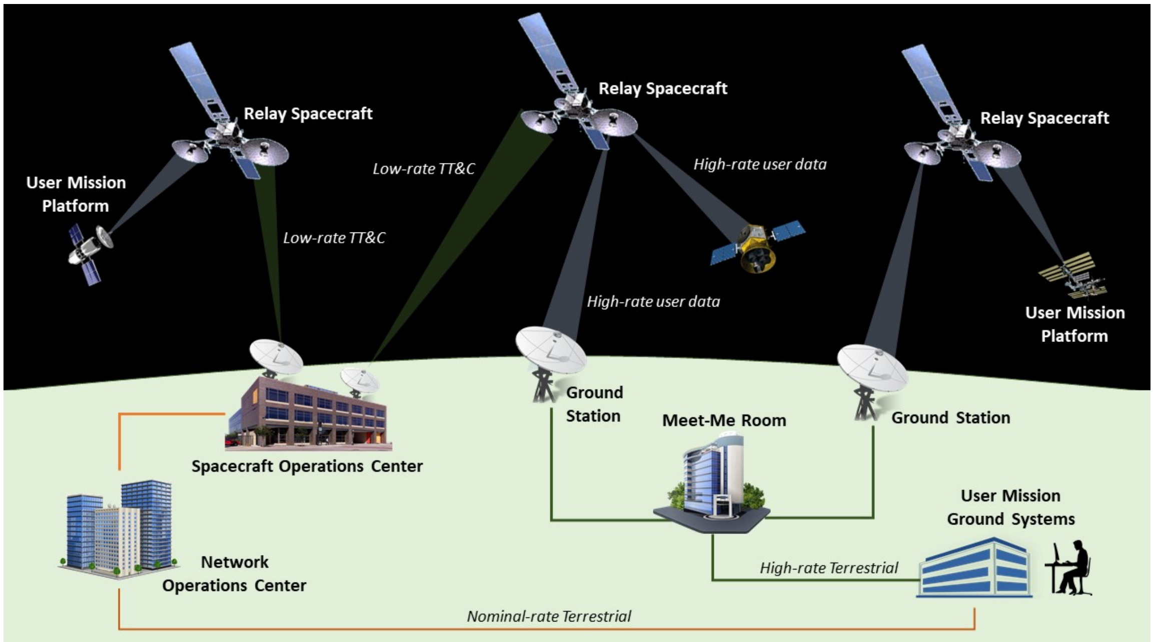

Figure 1.—Service Architecture Overview.

3.2.1 Service Planning

The service planning process includes activities to 1) negotiate service agreements with user missions, 2) to perform any necessary link, loading or other analyses and 3) to plan and allocate resources based on agreements. As an aid to this process, providers typically offer user missions with various service-related products via their service planning interfaces (e.g., user portals or other mechanisms). One such product is the service catalog, which provides a description of service offerings and related selectable options. Options may include data transfer protocols, security and encryption attributes, service guarantees, and others. The descriptions provided in service catalogs assist in mission preparation and project planning.

At the initiation of the planning process, the user mission and provider work iteratively to establish a service level agreement (SLA), which defines the service commitment and associated service provision parameters. SLAs commonly include many components, ranging from the definition of provided services to the conditions of agreement termination. The specific items within an SLA vary from provider to provider. There are, however, similarities, such as the following:

- Service Latency: the delay between the time of reception of user data at the provider ground system to the time of delivery of the user data to the user ground personnel (for return services).
- Service Availability: the probability that all planned data items that are transmitted via the service provider relay will be available to the user mission ground personnel with the required quality of data.
- Service Reactivity: the time delay from reception of service request from a user until the start of service execution.
- Service Planning Ratio: percentage of sessions accepted and scheduled by the service provider versus the number of sessions requested by the user.
- Service Execution Ratio: percentage of sessions successfully executed versus the sessions that are accepted and scheduled by the service provider.

As part of the planning process, additional analyses such as coverage and loading assessments may be necessary to determine the service provider's ability to support the user mission's needs. If necessary, the service provider may establish external agreements to aid in the provision of the services.

Once the service agreement is in place, the service provider prepares for the allocation and reservation of appropriate ground and space-based resources to deliver the requested services. The user mission personnel establish service agreements with terrestrial link providers for connectivity with the service provider's ground infrastructure. At this point, the user mission personnel are prepared to schedule space communications services through the provider's service scheduling interface.

3.2.2 Service Scheduling

The service scheduling process includes activities to develop top-level service schedules between the user mission and the service provider. Some providers may also include processes for lower-level scheduling of more specific resources or assets, such as specific ground stations, relays, or other infrastructure components.

In the future, NASA plans to allow for three methods of obtaining services for users. These methods include pre-scheduled, on-demand, and User-Initiated Service (UIS). A pre-scheduled service is the most common type of scheduling and refers to service that is scheduled in advance and relies on a mission prioritization method for conflict resolution. On-demand services are always available, even without a request, and are typically characterized by low/medium data rates. UIS involves the automated use of narrowband multiaccess links to request wideband single access services.

As part of the service request operation, the user specifies the requested service parameters, such as relay antenna number, start time of tracking, and initial position information (such as latitude, longitude, and altitude) of the target platform for signal acquisition. The user may also review and make edits to the schedule of requests on their assigned antennas. The provider's command center will validate the request, and then respond with the status and schedule for service provision. Once the service schedule has been established, the service execution process begins at the start of the scheduled service time.

3.2.3 Service Accountability Reporting

The service accountability reporting is a process that involves gathering, assessing, and providing information on the quality and quantity of service provision to user missions as well as any other relevant parties, such as the service provider's management teams. This information may be reported in real-time via the provider's service interface, or at other time intervals, depending on the service options. Specific reporting options and formats will vary from provider to provider.

3.3 Service Execution

Service execution involves the provisioning of forward and return data to/from the user mission platform through the provider's relay system and ground-based communications infrastructure. Prior to forward and return data delivery, the SOC configures the appropriate ground and space-based resources to prepare for service provision.

For forward data delivery, the user mission packetizes commands or other data items and applies encryption, if desired. The user then sends the forward data over terrestrial links to the provider's ground antenna systems. Once a communications link is established between the user mission platform and the provider's relay satellite, the ground antennas transmit the forward data to the relay satellite, which then transmits to the data to the user mission platform for reception and processing.

For return data delivery, the user mission platform retrieves data from onboard storage systems and applies encryption, if desired. Once the user platform and the provider's relay satellite establish communications, the user platform transmits the return data to the provider relay, which then transmits the data to the ground antenna systems. The user ground personnel can then retrieve its data from the provider's ground infrastructure via already-established terrestrial fiber links.

3.4 ConOps Summary

As mentioned, NASA is interested in a service concept of operations description for commercial space relay services and partnerships. While few of the providers are currently able to offer services to NASA users, the study participants proposed various service concepts that can meet NASA's anticipated space data relay needs, and emphasized the need for capability demonstrations to overcome technical hurdles and achieve the desired end state. The preceding sections described the proposed concepts for service operations.

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