NASA's and ESA's Tracking Networks, A Decade of Strategic Partnership for Solar System Exploration

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Planetary missions travel vast distances in the Solar System for valuable scientific exploration. Spacecraft return data to Earth via radio links that suffer power losses inversely proportional to the square of the distance, which forms a tremendous engineering challenge compounded by relatively low onboard transmitter power, typically 20 Watts at X-band (~8 GHz). Deep space missions are enabled only because leading space agencies invested in developing very large communications antennas as well as provided a sophisticated suite of tracking, telemetry and command standard services. NASA's Deep Space Network and ESA's ESTRACK network are distributed geographically to provide global coverage and utilize stations ranging in size from 34 meters to 70 meters in diameter. Over time, the expanding number of missions, increased requirements for redundancy during critical events as well as the drive for improved navigation accuracy via long-baseline interferometric techniques, increased the networks' loading and strongly motivated collaboration between the two agencies. Ten years ago, NASA and ESA established a cross-support agreement in addition to multiple on-going mission-specific agreements to meet this need. This *strategic partnership* was enabled by the development of international inter-operability technical standards and compatible spectrum usage. Over recent years, many critical events were supported via these agreements and some scientific breakthroughs were enabled. A multi-nation tracking contention period envisioned in the near future will also benefit from this partnership. Due to its success over the last decade, the DSN-ESTRACK partnership is serving as a model for other agencies with deep space communication facilities and similar interest. This paper reviews the benefits and lessons learned from collaborative deep space exploration, especially via communications networks, and discusses the potential implementation of similar NASA agreements with other space agencies.

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I. Introduction

Planetary missions operating at vast distances across the Solar System are possible only because leading space agencies invested in developing very large antennas for two-way communications as well as radio-metric tracking for navigation and science. The National Aeronautics and Space Administration (NASA) developed the Deep Space Network (DSN) over five decades ago and the European Space Agency (ESA) developed the ESTRACK network after the development of a European deep space program. These two networks are global with assets distributed in longitude to cover the entire sky; see Figure 1.

International treaties enabled the installations of DSN station complexes in Spain and Australia (in addition to the complex in California), and ESTRACK stations in Australia and Argentina (in addition to the station in member-state Spain), essentially making Spain, Australia, and Argentina strategic partners in prominent space programs.

Other space agencies, including those of Japan and India, have also developed deep space communications antennas within their national boundaries and have collaborated with NASA and ESA on deep space missions. Nations with upcoming plans for solar system missions and collaboration for deep space communications include S. Korea (lunar orbiter), the United Arab Emirates (Mars orbiter), and Israel (private venture lunar technology demonstration). Figure 2 illustrates the growing family of deep space stations.

Furthermore, countries that are members of ESA have their own national agencies, such as the Italian Space Agency (ASI) and the French Centre National d'Etudes Spatiales, (CNES), among others, independently collaborate with NASA on various deep space missions including the utilization of ground communications assets.

In addition to agency-managed communication assets, a small number of commercial entities have networks, some global, for Earth-orbiting mission services that occasionally make a contribution to deep space missions during the launch and early operations period due to the ability of their smaller stations to move faster than deep space stations and their locations that can fill coverage gaps at launch periods.

Deep space exploration, including human space flight, will not be limited to governments and large agencies in the near future. Private space companies, starting with announcements by SpaceX in the US, for example, are planning deep space missions that will likely lead to collaboration and partnership with the existing large communications facilities from NASA, ESA, or other service providers.

II. Motivation for Collaboration

The significant growth of the number of deep space missions and the increasing requirements for filling coverage gaps in any one network as well as providing back-up support during mission-critical events (e.g., landing on the surface of Mars) have motivated the agencies to collaborate and cross-support each other's missions under a series of agreements for strategic partnerships. Figure 3 illustrates an example of cross-support between two space agencies with deep space missions.

Standards in telecommunications systems, developed under various international bodies, enable such cross-support. Technical standards for data types, file formats, and scheduling format, for example, are developed by members of the Consultative Committee for Space Data Systems (CCSDS). The Interagency Operations Advisory Group (IOAG) is the leading forum for identifying common needs across multiple international agencies for coordinating space communications policy, high-level procedures, technical interfaces, and other matters related to interoperability and space communications.

The strategic partnership between NASA and ESA has proven to result in significant cost benefits, mission benefits, and general collaborative benefits. By meeting requirements for redundancy during critical events via utilizing existing partner assets to balance their needs, as opposed to developing their own, each agency realizes significant cost savings. By providing quick response time to mission events thus reducing the risks and enabling or enhancing the science return, each agency realizes significant mission benefits.

Collaborative benefits are manifested via fostering international collaboration to benefit the respective science communities for each agency, by imparting valuable experiences to teams on missions and ground networks from both sides and by sharing in the excitement of scientific discoveries that are passed on to constituencies and the public.

For NASA, for example, strategic partnerships and cross-support agreements serve the conditions of NASA missions needing non-DSN support, foreign or domestic, or Non-NASA missions, foreign or domestic, needing DSN support. The involved organizations can be governmental or government-sponsored agencies, private-commercial, or private-non-profit.

III. Historical Development

NASA has been directed by the *1958 National Aeronautics and Space Act* to cooperate with other nations and disseminate information widely with the objective of "cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results." The 2010 National Space Policy calls on the agency to expand international cooperation "on mutually beneficial space activities to broaden and extend the benefits of space, further the peaceful use of space, and enhance collection and partnership in sharing of space-derived information."

Furthermore, NASA has recently been reaching out to non-traditional partners with more limited national resources. Currently, NASA has approximately 600 international agreements with half of them with various partners throughout Europe. Two-thirds of these agreements are in science missions.

With these objectives, the first set of deep space tracking stations forming NASA's DSN, managed by the Jet Propulsion Laboratory, California Institute of Technology, became operational in the early 1960 in time to support the first planetary mission, the Mariner 4 Mars flyby in 1964 [1]. The DSN has since been increasing the number of stations at each complex in its network and continually evolving in technical capabilities to meet increased requirements for higher data rates and radio-metric precision [2].

ESTRACK was developed over 42 years ago in response to ESA's needs for a European network to support ESA's planetary and deep space missions. The network has evolved to support deep space missions with three 35-meter diameter stations in a global configuration (Figure 2).

IV. Types of Strategic Agreements

In general, strategic partnerships reflect the spirit of collaborative relationship between space agencies. In practice, such collaboration is manifested by different types of formal agreements between the partners, typically at governmental levels, that depend on several factors including national and international legal requisites, provisions for exchange of funding, length of agreement time, speed of finalizing an agreement relative to the upcoming need for support, and specific mission requirements. The benefits of the various agreements impact the following factors:

- Science requirements
- Engineering specifications and standards
- Technologies or advanced capabilities developed, installed, and tested
- Operational procedures and practices

As a result, care is taken in assessing the technical feasibility with each of these four communities (science, engineering, technology, and operations). Support typically starts from driving science requirements that are translated into engineering specifications as well as consideration of any new or advanced capabilities, and then the development of operational procedure; agreements end up reflecting this process.

A variety of governing agreements form the basis of implementing the partnership in a mutually beneficial manner, such as:

- Cross-support agreements
- Stand-alone, mission-specific agreements
- Reimbursable agreements
- Handshakes!

The government-level documentation at NASA include (also see Figure 4):

- Technical Assistance Agreement
- Commerce agreement or license exception
- Space Act Agreement
- Other: Implementation Agreement, Technical Understanding, etc.

V. Cross Support Agreement

The leading governing document between NASA and ESA collaboration on tracking services is a Cross Support Agreement (CSA) where a cross-support service is defined as either NASA resources supporting an ESA mission, or ESA resources supporting a NASA mission. Technical details are included in an accompanying document called the ***generic*** Operational Interface Control Document (OICD) that describes capabilities, systems, processes, and interfaces that can apply to spacecraft from either agency utilizing standard, or generic, services. As missions sign up for the services through the CSA and provide unique requirements, a brief mission-specific document is developed, reviewed, and approved, as described below, to supplement the CSA and OICD without repeating their standard contents.

While some literature and international fora often refer to the process of ground assets of one agency supporting a space mission of another agency as "cross-support," NASA and ESA make a distinction between services provided under the CSA and services provided under other stand-alone agreements (discussed below), where only services under the former are specifically called "cross-support." This is important because the CSA requires a balance in the accounting of provided tracking hours by each agency; only CSA-type of cross-support hours are accounted for in the cross-support balancing process. Other provisions are applied to the hours utilized under stand-alone agreements.

The CSA establishes the conditions for providing reciprocal support between ESA and NASA and does not include provision for services to any other end users such as third parties, other nations, or non-governmental entities. For the latter cases, if a direct agreement or a third-party contract is in place between the end user and the supporting agency, the technical approach and interfaces in place for the CSA could be used on a case-by-case basis and with advanced approvals of the two Cross-Support Liaison Officers at NASA and ESA.

NASA and ESA signed the CSA ten years ago and recently agreed to renew it for another decade without modification, a testament to its success. However, a supporting document was created, called the Cross-Support Management Guidelines document, that provides guidelines for managing services between the two agencies in light of evolving mission requirements and accounting for balancing the provided hours of service. In the spirit of the CSA, the provision of reciprocal services should balance within an agreed-upon period (e.g., annual).

The following types of network and operations cross-support services are governed by the agreement's management guidelines:

1. Tracking, Telemetry, and Command (TT&C): the bi-directional TT&C interoperability features provide risk-reducing benefits to missions by:
    (a) providing support during mission critical events in the event of non-availability of the prime tracking station due to severe local weather interference, natural disasters, or other unanticipated barriers to the scheduled support
    (b) providing support during mission critical events as a hot back-up to the prime station, as required by the mission
    (c) providing support during mission critical events in the event of coverage gaps due to geometrical view periods
    (d) alleviating tracking network over-capacity and over-demand
    (e) providing navigation and Radio Science radio-metrics especially those requiring long baselines for Delta Differencing One-way Range (DDOR) and Very Long Baseline Interferometry (VLBI)
2. Mission Operations and Ground Data Systems: this encompasses the monitoring and control of a space mission throughout its lifetime and includes planning, execution, analysis and reporting of spacecraft, payload and ground segment activities. In addition to the TT&C services described above, this includes:
    (a) scheduling services,
    (b) mission operations services and ground hardware and software data systems
    (c) mission relay operations services, including the UHF link between orbiter and lander and ground delivery of relay data

As mentioned above, each agency names a CSA Liaison Officer and a Service Manager or Task Manager from the supporting network, also known as the Cross-Support Manager. Between the Liaison Officers and Service Managers, the responsibilities carried out include:

- Assessing the technical feasibility of cross-support requests
- Examining compliance (or exceptions) with the NASA-ESA generic Operational Interface Control Document (OICD)
- Ensuring a complete review of the requirements and constraints, especially network loading
- Estimating and identifying the necessary resources and their availability
- Preparing the Implementing Arrangement for management endorsement and formal agreement by the liaison officers
- Monitoring the preparation, implementation, and validation of the agreed support services
- Interfacing with the missions as the primary point of contact (Service Manager).

The process is carried out via the following steps:

1. Initial service request in a timely fashion (except for emergency support)
2. Review of technical feasibility that can include engineering teams from the respective agencies
3. Formalization of the cross-support request via a letter from the Liaison Officer that documents the requested loading profile and high-level technical requirements
4. A written response from the Liaison Officer of the service provider agency.
5. Development of formal documentation: after a cross-support request is approved by both agencies, the service-provider agency is responsible for writing an Implementing Arrangement Document (IAD) or DSN Service Agreement (DSA) that details the required services and priorities.

The new document on implementation guidelines has its biggest contribution to the process is using lessons learned and historical data from a decade of experience to provide improved accounting formulae. Regular ground tracking services account for actual hours of scheduled station time including the scheduled setup and teardown times. However, non-generic services include effort spent to define, implement, validate systems then conduct the mission operations, as specified by the requesting agency and documented in the IAD/DSA. This is typically due to a higher criticality of the support or more complex mission scenarios.

Scheduled station hours for such critical events are worth more than the same number of hours during routine, or generic cross-support hours. For example, supporting 4 hours during a launch, orbit insertion, or landing event requires more effort and does not simply balance 4 hours of generic tracking during a routine cruise phase. As a result, a special formula was developed and documented. In addition, the DSN has different internal accounting guidelines for NASA and non-NASA missions for usage of the 70-m stations versus the 34-m stations.

For these purposes, the value of ground tracking services is defined in a fictitious currency called "Cross Support Agreement unit" (CSAu), associated with a ground station tracking hour. A **weighting factor** scales this unit up for the additional engineering effort required for the cross support. The CSAu is intended to capture what typically counts for the provision of this service, i.e., not only the effort to operate the ground station in real-time, but also the effort spent in planning, documenting, engineering, implementing and validating the system configuration and operational interfaces for the cross support - - for the previous example 4 CSAu (units or hours) of a mission-critical landing support would be balanced by 4xW CSAu of routine cruise support, where W is the agreed-upon weighting factor.

Historical data for tracking services show a relatively well- defined pattern for the ratio of tracking hours to engineering effort depending on the type of support. This data has been used to derive the value of the CSAu detailed in the implementations guideline document.

VI. Stand-Alone Strategic Agreements

It is common for any two space agencies (such as NASA and ESA) to sign an agreement specific to the exchange of services to meet mutual needs to carry out a specific space mission by one of the agencies without exchange of funds. For example, if ESA plans a future mission to planetary target and NASA proposes a NASA-provided payload to be carried on this mission, in return, the agreement could provide provisions for providing DSN support "service" to the mission to balance the "service" of carrying the payload.

The Cassini-Huygens program to Saturn is an example of a sophisticated agreement between NASA, the primary mission provider and manager, and ESA, which provided the Huygens probe, and separately with ASI, which provided the high-gain antenna and some radio and radar components. Sundararajan [3] examines such case studies of interplanetary missions for evaluating international partnerships to further "analyze the space policy goals, science objectives, economics and the cooperation mechanism."

These agreements can be Memoranda of Understanding (MOU), Letters of Agreement (LOA) or other forms of agreements. As noted above, although they meet the spirit of the "cross-support", these stand-alone agreements are more general strategic partnership agreements with their own self-contained conditions and accounting. They do not fall under the CSA although they could include provisions similar to those in the CSA. NASA's Office of International and Inter0agency Relations (OIIR) coordinates all types of strategic agreements for NASA.

VII. Reimbursable Strategic Agreements

Since cross-support agreements and stand-alone strategic agreements do not involve exchange of funds between agencies, there are occasions where a space agency secures agreements for support by a tracking network in exchange for direct funding. Examples of these reimbursable agreements include the Indian Space Research Organization (ISRO) missions to Mars and the Moon and the planned United Arab Emirate Space Agency (UAE-SA) Hope mission to Mars (agreement in place).

Such reimbursable agreements are not simple contracts but remain strategic and selective in nature. For NASA, they require federal government approval, a Task Plan, and a Space Act Agreement approved by both agencies. However, there are many commonalities between this type and the previously discussed types of agreements. Once strategic considerations and approvals have been secured, the strategic partnerships manager (can be the same person as the cross-support manager) applies the same type of technical feasibilities and network loading studies and assess the cost of the requested support.

VIII. Strategic Handshakes

There are occasional cases of strategic partnerships that require the minimum amount of agreements and documentation, called handshakes for deliberate over-simplification! For example, there have been occasions where supporting the Entry, Descent, and Landing (EDL) event for Mars missions required the utilization of large radio telescopes worldwide [4]. These telescopes are not owned or operated by space agencies (typically other government agencies, non-profit organizations, or universities). Since these activities are rare for the telescope, are very limited in scope and duration, and are agreed upon on best-efforts research-type of effort with no exchange of funds, then a simple exchange or letters is satisfactory to proceed with providing the support.

IX. Accomplishments to Date and Future Goals

NASA and ESA celebrated ten years of a successful cross-support agreements and several decades of a general strategic partnership. Numerous missions have benefitted from this partnership resulting in reduced mission risks and enhanced scientific return.

The successful strategic partnership between NASA and ESA is serving as a model as similar agreements are proposed with other space agencies. Lessons learned and accounting process improvements, such as those discusses above, can be applied to improving the processes as needed in the future with all partners.

The Sardinia radio telescope, for example, is in the process of converting their system to become a fully functional 64-meter diameter deep space antenna. In the process one or more types of strategic partnerships with NASA, and possibly with ESA, can be developed using the experience obtained to date; see [5].

Goals for the near future include making the strategic partnerships process invisible to mission users. Missions planning future cross-support activities can contact the Service Managers to make such arrangements and discuss the most suitable type of agreement.

Additional goals include expanding the collaboration to future technologies such as advanced radio-metric and Radio Science techniques and instrumentation, optical communications, CubeSats platforms, and others in order to gain the same benefits realized so far as systems evolve to support future missions.

X. Conclusion

Solar system exploration missions from NASA and ESA have benefitted from collaboration and partnerships that enable NASA's Deep Space Network and ESA's ESTRACK network, which are distributed globally, to provide coverage to missions throughout the sky. Over recent years, many critical events were supported via these agreements and some scientific breakthroughs were enabled. A multi-nation tracking contention period envisioned in the near future will also benefit from this partnership; see [6].

Due to its success over the last decade, the DSN-ESTRACK partnership is serving as a model for other agencies with deep space communication facilities and similar interest. Half a dozen nations were discussed in various forms of partnership as either space agencies with missions that can benefit from NASA and ESA stations, or nations with ground stations that can potentially support NASA and ESA deep space missions.

Deep space exploration, will not be limited to the purview of large agencies in the near future as private space companies, are planning deep space and planetary missions including crewed ones, that will likely lead various forms of collaboration and partnership with the existing large communications facilities from NASA, ESA, or other service providers.

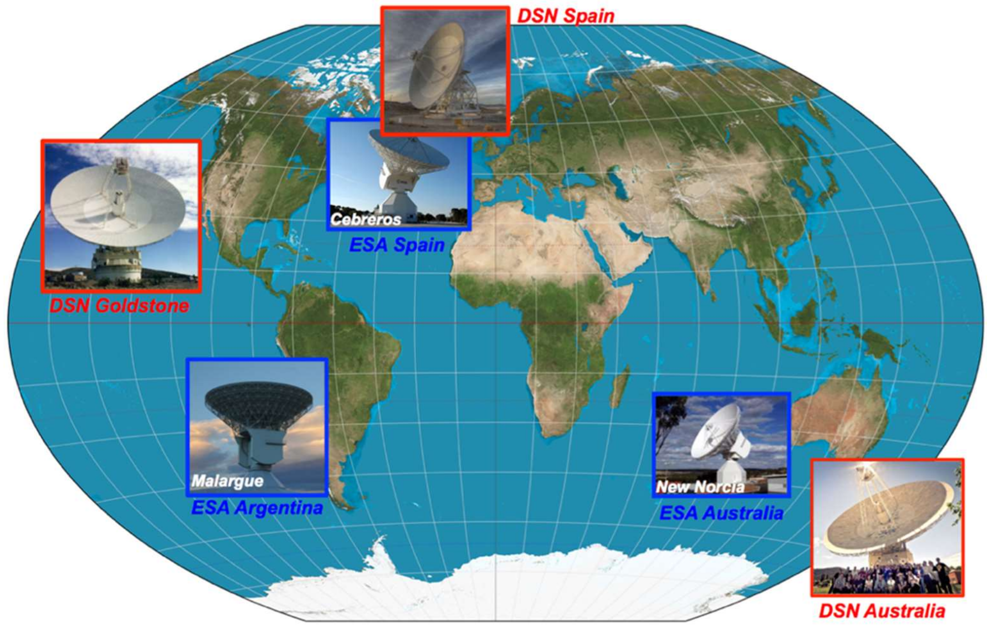

Fig. 1: Locations of three DSN complexes, each with multiple large stations and ESA deep space stations around the globe. Location distribution is by design along Earth's longitude lines to cover the entire sky past a certain distance from Earth, thus allowing constant coverage as the Earth rotates. Northern vs. Southern hemisphere locations also allow optimizing views for missions that can be inclined in the Northern or Southern parts of the ecliptic plane.

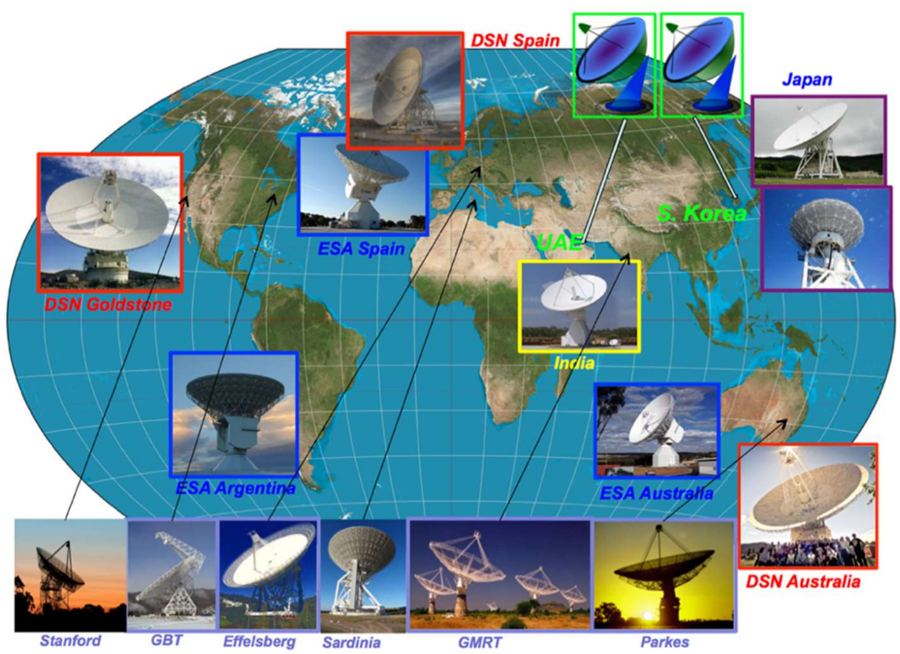

Fig. 2: The NASA and ESA stations from Figure 1 with additional stations from India and Japan as well as conceptual possibilities for future stations in the Korea and elsewhere. Also shown are a number of very large radio telescopes that have participated in the support of robotic deep space missions or, in the case of the Sardinia radio telescope, are being modified as deep space tracking antennas.

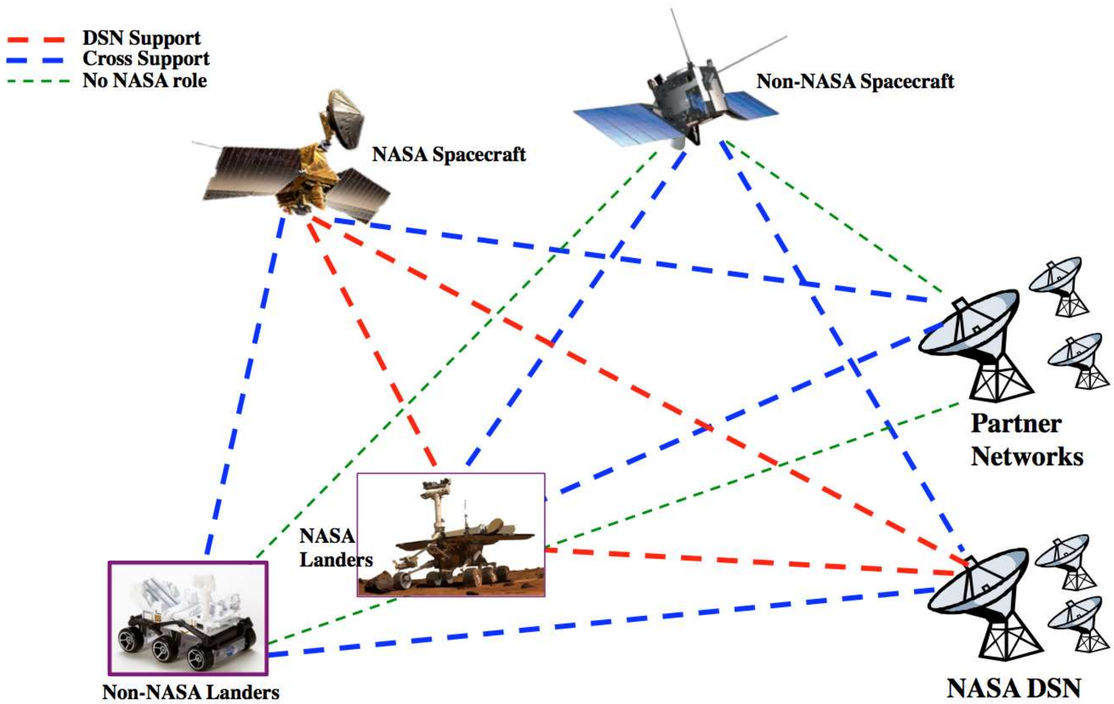

Fig. 3: Illustration for Cross-Support between two space agencies with deep space missions.

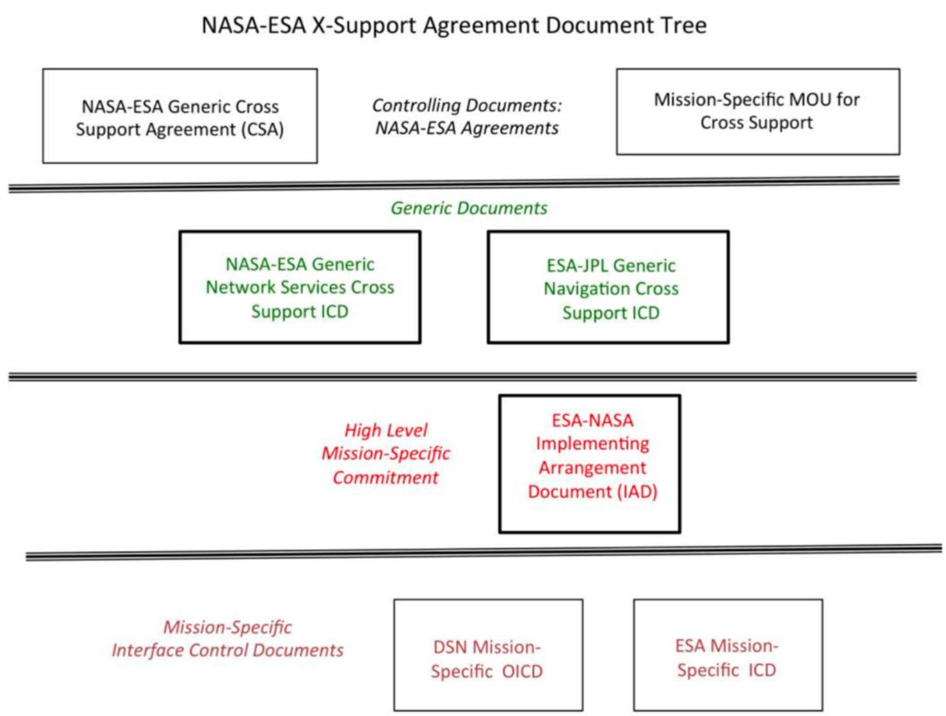

Fig. 4: Illustration of some of the various documents utilized in the NASA-ESA Cross-Support Process

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References

[1] Mudgway, D., *Uplink-Downlink: A History of the Deep Space Network, 1957-1997*, NASA SP-2001-4227.

[2] Deutsch, L. J., Townes, S. A., Liebrecht, P. E., Vrotsos, P. A., & Cornwell, D. M., “Deep Space Network: The Next 50 Years.,” 14th International Conference on Space Operations, 2016.

[3] Sundararajan, V., “A Case Study of Interplanetary Missions for Evaluating International Partnerships,” AIAA Space Conference & Exposition, 2009.

[4] Asmar, S.W., S. Esterhuizen, S., Gupta, Y., De, K., Firre, D., Edwards, Jr., C. D., Karatekin, Ö., and Ferri, F., “Direct-to-Earth Radio Link from the ExoMars Schiaparelli Lander,” International Planetary Probe Workshop, the Hague, 2017.

[5] Flamini, E., Iacolina, N., Impresario, G., Parca, G., Russo, E., Valente, G., Viviano, S., Asmar, S., Guerrero A., “The Sardinia Deep Space Antenna: Capabilities and Planned Operations of DSS-69,” Space Ops Conference in Marseille, France, 2018.

[6] Lichten, S., Abraham, D, Arroyo, B., Asmar, S., Bell, J. and Edwards, C., “Allocation of Deep Space Network Ground System Tracking and Communications Assets During the 2020-2021 Timeframe of the Mars Armada,” Space Ops Conference in Marseille, France, 2018.