Distributed Deep Space Data Network

George R Tyson, Manager
BNRC LLC, Colorado City, Texas 79512, USA
gtyson@bnrc.tech

As humanity pushes into space, the acquisition, storage, and processing of data will be paramount. The data will indicate the best routes, practices, and procedures to move forward with permanent habitation of space. Without it, humanity will be groping in the dark, inviting unmitigated dangers to consume us.

The current issue with acquiring and managing the needed data is communication. The NASA Deep Space Network (DSN), which is the network where all extraterrestrial data is collected, is already oversubscribed and underfunded. This problem will only increase as more missions are added each year. Expanding the existing network only postpones the inevitable collapse of the overwhelmed system. A new architecture needs to be developed that uses in-situ resources and is funded in a different manner than the current systems. BNRC is proposing a Solar System wide Distributed Deep Space Data Network (DDSDN) that uses an internet - Cloud Computing provider funding model.

The DDSDN would have distributed nodes throughout the solar system that are connected through a mesh type network and provide services similar to terrestrial cloud computing systems. This network could be accessible from anywhere in the solar system and would provide data storage, computing on demand, and Software as a Service (SaaS), as well as navigation. Construction of the nodes would utilize resources from the Earth, Moon, and Mars. While the funding would be achieved by a public-private partnership and service fees.

Introduction

Before humans ventured into space, data was collected to better understand the environment and to assist with the development of future missions. At first it was Earth based sensors such as optical and radio telescopes, then satellites and finally probes to other bodies in the Solar System. As human ambitions grow, so does the need for data.

As humanity migrates out into the Solar System, the need for data will increase exponentially. This will include data collection, storage, processing and finally delivery to users anywhere in the Solar System. The current systems of extraterrestrial data collection, used by the United States and other countries, was developed over six decades ago[1] and while they have been expanded and updated, they still operate on an outdated architecture model. For humanity to get the data it needs, the data collection system needs to move to a modern architecture.

Need for Data

In support of the Moon mission in the 1960s, the Jet Propulsion Laboratory (JPL) developed and launched a series of probes (the Surveyor and Mariner series) designed to collect data on the Moon's surface.[2] It was this data that drove the design of the Moon lander and helped shape the Moon landing missions. It was transmitted over JPL's Deep Space Network, which was a forerunner of NASA's Deep Space Network (DSN).

Every manned mission in the 1960s was in support of the Moon missions. Each flight was designed to collect data that helped the engineers on Earth to better understand the space environment and its effects on man and machine. Without this data, the manned Moon landings may not have occurred or been successful.

Today we are still using manned and unmanned missions to collect data for a better understanding of space and other planets' environments. This data will be used to plan future missions that will include the use of extraterrestrial resources, habitation, and colonialization. It is the data currently being collected through the DSN that will make future missions possible and successful.

NASA DSN

The NASA Deep Space Network (DSN) consists of three major facilities located approximately 120° apart in longitude, around the world.[3] The placement of these sites allow almost constant communication with distant spacecraft as the Earth rotates, as the spacecraft goes below the horizon on one location it rises on another. Each site is made up of multiple large antennas equipped with ultra-sensitive receiving systems which are remotely controlled from a processing center at each complex.

The DSN is a crucial link to spacecraft in the far reaches of the Solar System. All data, commands, software updates, etc. go through the DSN. As more missions fill the sky, the greater the demand placed on the DSN.

The DSN is critical for multiple organizations including NASA. Europe's European Space Agency (ESA)and the Japan Aerospace Exploration Agency (JAXA),[3] but it has a problem. From the NASA Inspector General's (IG) report:[4]

> NASA's DSN is currently oversubscribed and will continue to be overburdened by the demands created by an increasing number of deep space missions, including crewed and robotic missions. Presently, the Agency's DSN is responsible for communication and navigation support for nearly 60 NASA and international space missions. According to Agency internal capacity and loading studies, demand for DSN support will increase dramatically in the coming decade with excess demand for hours on the DSN reaching about 50 percent by the 2030s.

In conclusion:

> NASA's DSN is vital to providing the communication links for the Agency's most complex and expensive space exploration missions such as the JWST and the Agency's Artemis lunar campaign. Nevertheless, the network is at times more than 40 percent oversubscribed and has suffered from outdated infrastructure for decades. These deficiencies have led to missions not consistently receiving the DSN support they require, thereby reducing their return on investment. NASA has sought to revitalize the DSN by upgrading existing infrastructure and building new antennas, but efforts have been slow to materialize and are not likely to keep pace with the Agency's growing number of deep space missions and their increasing data demands. As the Agency looks to the future and crewed missions to the Moon and Mars, maintaining a robust and reliable DSN is essential to meeting these missions' needs.

Nasa's plan to overcome the issues, from the IG's report:

> NASA's primary solution to address the DSN's unmet demand is the additional antennas and upgrades ongoing and planned under the [Deep Space Network Aperture Enhancement Project] DAEP. However, as previously stated, DAEP is nearly 5 years behind schedule and Agency officials have stressed that even with those planned upgrades DSN capacity will be insufficient to meet current and future mission demands. According to internal studies, the Agency may need at least two more 34-meter antennas at each of the three sites to meet projected demand by the 2030s.

As stated by the IG, even if NASA can complete the site upgrades the DSN will not be able to meet demand, and it never will, if it follows the architecture developed in 1958. Also the current architecture is Earth based and communications can be blocked by the Sun[8] or planets[9]. What is required is a new architecture that can meet the current and future demands, as well as not being blocked by celestial bodies. What is needed is the Distributed Deep Space Digital Network (DDSDN) proposed by BNRC.

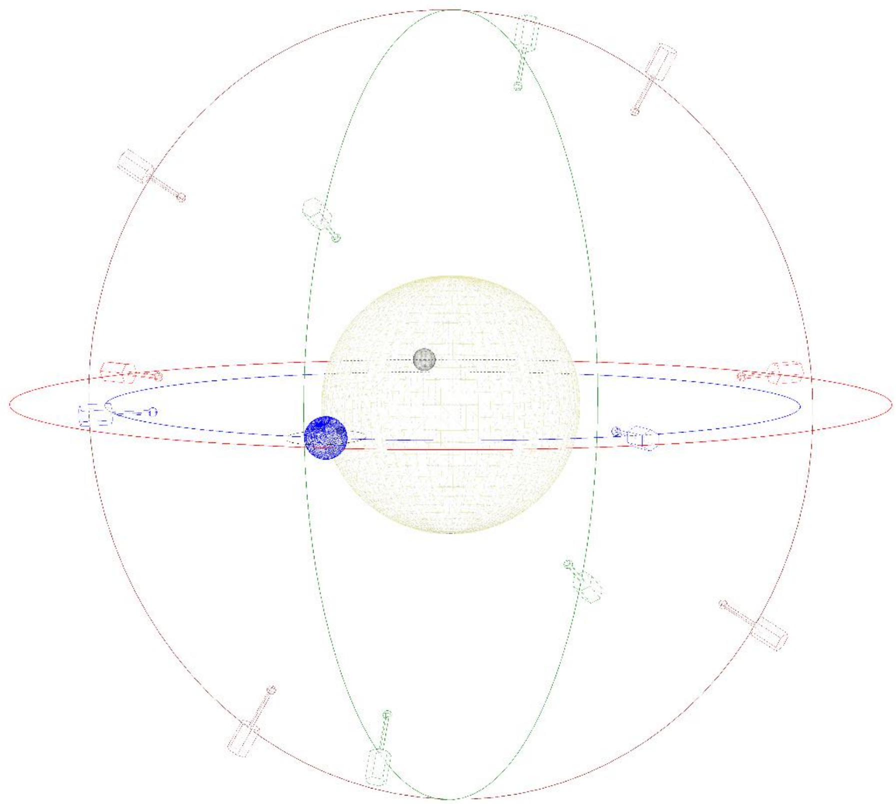
DDSDN (Distributed Deep Space Digital Network)

A new architecture needs to be developed and implemented that can meet current and future needs. The following rules must be met for it function properly:

1. The network must be accessible from all parts of the Solar System.
2. The network must be redundant and robust against both natural and manmade failures.
3. The network must be easily expandable. As humanity pushes out into the Solar System new assets need to be easily added.
4. The network must service all devices whether maned vehicles, satellites, probes, or even small standalone sensors.

To meet these requirements, the architecture must be designed with a backbone (Tier 1) that allows Line of Sight (LoS) to most of the solar system and have modularity which can be expanded in areas of high interest and activity. The backbone will consist of 8 platforms in two solar orbits perpendicular to the orbital plane and to each other. Each orbit will consist of four platforms separated by a quarter arc. This will provide LoS to a minimum of two and a maximum of six platforms from anywhere in the solar system. The platform orbits will intersect the orbital plane between Earth and Mars, 189 million kilometers from the Sun, providing an orbital period of 521 days.

The orbit of the backbone provides the greatest LoS coverage of both inner and outer Solar System with minimal distance to the greatest area of human activity.

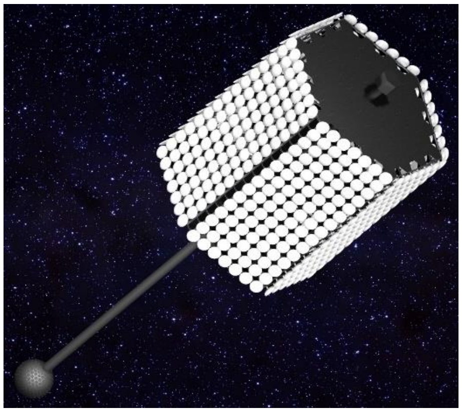


Orbits of the DDSDN network. Tier 1 green and purple. Tier 2 red (Mars orbit) and blue (Earth orbit). Tier 3 not shown.

While individual platforms can be blocked by the Sun, others will be visible in different positions on the arc.

For areas of high activity/interest such as areas around the Earth and Mars, two additional platforms will be added for each location (Tier 2). They will be aligned in the body's planetary orbit with one platform proceeding and the other following. Additional small satellite networks, similar to the Starlink system, will be set up around the celestial bodies providing links to Tier 1 through Tier 2. Tier 3 will be satellite networks orbiting planets, moons or large asteroids providing access to the network from anywhere on the surface. Missions outside of areas of high activity or areas without small networks will communicate directly with Tier 1.

The theoretical DDSDN Platform is a hexagonal tube with each face measuring 500 meters in width. The tubes length is approximately one kilometer which equates to



a structure that is approximately a cubic kilometer (not including the gravity stabilizer). Each platform will have 630 seventy-meter dishes that can operate independently or in groups along with computing power for dish control and data storage/processing, pressurized habitat, docking ring, various other types of transmitters/receivers (including lasers), and a nuclear power station (located in the gravity stabilizer).

All platforms and celestial body satellite constellations will communicate as a partially-connected mesh network [5] to provide robustness and redundancy. The platforms in high activity/interest areas will have additional computing resources for a more extensive offering of cloud computing, [6] and Software as a Service (SaaS)[7] products.

Advantages of the DDSDN Architecture

The DDSDN architecture provides redundance against signal jamming, loss of platforms, reduced capacities and most natural or manmade catastrophes by providing multiple signal paths. From the majority of the Solar System, a device will have LoS to multiple platforms or relay satellites. Only probes/ships in a close orbit or on the surface of a celestial object without a Tier 3 system could lose contact with the network while LoS is blocked.

The open nature of the architecture allows for additional relay satellites or platforms to be added at any time, providing additional resources to missions. This would be for the prevention of LoS to the DDSDN system, or to meet additional computing power requirements, or to provide additional bandwidth.

Data processing is a large part of any mission and is currently done on Earth. The ability to access powerful computing systems integral to the platforms, or attached to the network as additional resources, allows missions to have access to data processing without the power drain or the need to transport additional resources. It also provides an easy means to share raw and processed data with all users across the Solar System.

Navigation and timing, similar to GPS, can also be supported by the architecture. LoS can be established with multiple nodes (platforms, satellites, etc.) anywhere in the Solar System. In deep space the main DDSDN platforms would provide the reference, while areas in and around a local network system would have a higher number of reference points, resulting in higher resolution navigation.

As mentioned earlier, the DDSDN architecture can provide solar system wide timing, which will be essential for data collection and processing. To achieve the precision and fidelity necessary for accurate data collection and comparison across the solar system, clock technology must improve. NASA, as well as others, are working to develop new exceedingly high precision clocks along with new ways to determine time from celestial events.

The timing aspect of data collection and comparison is paramount when comparing data from disparate points across the solar system. Data with a universal time stamp can be compared to find Solar system wide events and how they affect the local sensor area. An example would be a Solar flare. Universal time stamped data from across the Solar system would allow the tracking of the particle wave and its affects.

Disasters

As a distributed partially-connected mesh network the architecture has built in robustness, it will still operate if a node or an entire layer is disabled. One of the many dangers posed to communications in space are Solar flares, which can disrupt operations or even destroy equipment. If one or more backbone platforms are disabled due to a solar flare, the other operational platforms could reroute data traffic. Performance may degrade but the system would still be functional.

If a Tier 3 layer is disrupted, such as what would happen if something insane occurred such as a nuclear explosion in Earth orbit,[11] the rest of the network will operate normally. Data will be saved to the network cloud and accessible once the local Tier 3 layer is brought back online. The architecture also provides easier recovery for the local Tier 3 layer. Complete restoration is not required for service to resume. It can be restored in increments, providing better throughput as new resources become available.

Construction of the DDSDN platforms

The size and mass of the platforms makes them cost prohibitive to construct using traditional methods. The transportation costs of sourcing all materials from Earth makes large space construction projects cost prohibitive, even when using reusable spacecraft such as SpaceX's Starship. To make large scale space construction affordable, In-situ resources must be utilized as well as innovative construction methods. Orbital Construction Pioneers, Inc. (OCP) is currently developing a material and process that could be used to construct the DDSDN platforms.

The patent pending process with Stellamer material provides a method to rely on in-situ resources for production and creates a platform that exceeds a mass of 64 million tonnes. The size and mass make a robust structure without lifting everything from Earth.

OCP Stellamer is composed of over 70% Moon regolith, or material sourced from any celestial body, and is used in a special additive manufacturing process. The process can construct hexagon, pentagon, square, or circle components 100 meters across and a meter thick. A separate custom process can create beams from Stellamer of any length. These components can be affixed into any shape or size creating the platforms.

Financing

The scope and size of the DDSDN architecture will require public-private investment for its creation, much in the same way the internet has been developed.[10] The funding for the research and development of both the DDSDN architecture and the construction infrastructure necessary for the sourcing of in-situ material world be provided by governments. As the technology is proven and the network develops, private enterprises will enter the market in support of private missions or in the prospect of profiting from offering computing and data services.

A key element to the affordability of the DDSDN is the use of in-situ resources, but this will require infrastructure that can mine, refine and transport the materials required for construction and the care of the labor force. This infrastructure will grow as the DDSDN network is built. Initially the justification for the infrastructure will be the construction of the DDSDN network, but just as has been done on

Earth, it will be repurposed or tasked to support other projects. Making the DDSDN network the initial impetus to extraterrestrial mining, processing, manufacturing and industrialization.

The cost to create the infrastructure would be initially borne by governments and very large multinational corporations. As the DDSDN network is built, the infrastructure will be used for additional tasks, providing opportunities for smaller corporations and groups to add additional capabilities in support of diverse missions. The construction of the DDSDN architecture will be used as the primary reason for infrastructure financing, but the true use of the infrastructure will be for the expansion of human habitation and the exploitation of resources for projects other than the DDSDN architecture.

Additional opportunities for private enterprise become available as the DDSDN architecture is put in place. Private companies can begin to offer cloud-based services, data analysis services and even sensor development/deployment. Any service that is currently internet based on the Earth will move into space and be offered through the DDSDN network. All these activities will produce income and increase the use of the DDSDN architecture.

Thus, the DDSDN network becomes an income driver for many corporations and individuals, along with an effective communications and navigations system for governments and private space-based missions.

Summary

As humanity expands out into space the need for, and creation of data will grow exponentially. The current deep space network architecture is outdated, oversubscribed and will be unable to meet future needs. A new architecture that is Solar System wide, such as the Distributed Deep Space Digital Network (DDSDS), is required. The network would use a combination of large platforms and smaller satellites to provide Solar System wide coverage. The cost of the DDSDN would be met using a public-private financing model much in the same way the ground-based internet was developed. Governments would finance the initial research and infrastructure development while corporations pay for the buildout of the network.

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