18th International Conference on Space Operations, Montreal, Canada, 26 - 30 May 2025.

Considerations in Building a DSN-Affiliated Ground Station in Economical and Sustainable Ways

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Abstract

The 21-m ground station at the Morehead State University became operational in 2021 as an affiliated node of the NASA Deep Space Network (DSN). The station was developed to support NASA-sponsored CubeSat missions such as CAPSTONE and the Artemis-1 Cubesats (e.g., Lunar IceCube). Since then, it has been used to support other lunar commercial missions such as Intuitive Machine's IM-1 and IM-2 landers. Continued support for future missions both commercially and NASA-owed missions is expected.

This paper will discuss some of the desirable characteristics of a DSN-affiliated station. Given that the affiliated station is likely owned and operated by a university as in the case of Morehead, funding is often limited. The approach taken during the development to realize an operational ground station within the available budget is discussed. More importantly the need to maintain such an operational system post-deployment is challenging. Different strategies employed by the Morehead State University team are discussed. They include expanding the station capabilities and offering services to other potential mission users to sustain operational funding.

1. Introduction

The 21-m ground station at the Morehead State University was approved for operations in 2021 as an affiliated node of the NASA Deep Space Network (DSN). Designated as the NASA Deep Space Station DSS-17, it is the first and thus far the only station that has the distinction of being affiliated with the DSN. The station development was originally funded to support NASA-sponsored CubeSat missions on the Artemis-1 mission, primarily for the Lunar IceCube, Lunar Flashlight, Lunar Polar Hydrogen Mapper (LunaH-Map) Near Earth Asteroid Scout (NEOScout) and Cubesat for Solar Particles (CusP). The station has since been routinely supporting the NASA-sponsored Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) mission in the near rectilinear halo orbit around the moon, as well as the recent commercial missions such as the Intuitive Machines IM-1 Odysseus and IM-2 Athena lunar landers. Support to future NASA and commercial missions is expected to continue since the station is well suited for tracking fast moving, low transmitting power small satellites in low Earth orbit as well as satellite at geostationary, lunar and Earth-Sun Lagrange point orbits. In addition to spacecraft tracking, the Morehead also serves as a testbed for technology demonstration of new mission operations concepts.

This paper discusses some considerations in the building and maintaining the operation of a DSN-affiliated ground station such as in ways that are economical and sustainable. This is particularly applicable for cases in which the station is owned and operated by a university with limited funding resource. In section 2, key desirable characteristics of DSN affiliated station are discussed. Section 3 reflects the system architecture of Morehead station with close integration with the DSN. Section 4 presents some strategies taken to economize the development cost of the station. Section 5 discusses various approaches to sustain the system operations.

2. DSN Affiliation

A DSN affiliated station refers to a ground station that is owned and operated by an organization external to the DSN but it could serve as a DSN antenna to support DSN mission users at time of need. The most distinguished feature of an affiliated station is the station appears as one of the DSN nodes of operations. Mission users can use the affiliated station the same way they use the DSN stations. The affiliated station has common interfaces, and operational processes, with mission users in requesting antenna services, receiving telemetry data from spacecraft as well as transmitting command data to spacecraft. This aspect eliminates any change required on the mission users.

To achieve the common interfaces, the Morehead 21-m station is well integrated with the DSN infrastructure and can appear to mission users as one of the many DSN antennas. As seen in Figure 1 [1], interfaces between the

Morehead tracking station and the mission operation center are the same as with other DSN antennas. Data delivery and service requests are handled by the DSN Network Operation Center at the Jet Propulsion Laboratory (JPL) in Pasadena, California. These common interfaces include preparation activities for tracking services such as antenna scheduling, submission of spacecraft ephemeris as well as delivery of telemetry, tracking and command data. Specifically, the DSN Network Operation Center enables mission users to:

(1) Schedule a track with Morehead station in the same way it does with any other DSN antennas.
(2) Submit spacecraft ephemeris for computation of view period and generation of antenna pointing and signal Doppler frequency that are required for tracking at Morehead.
(3) Receive telemetry and tracking (Doppler & ranging) data in the same way as other DSN antennas.
(4) Transmit command data to spacecraft. The connection and flow of command data is directly with the uplink controller at Morehead – the same way with DSN stations; however, the DSN Network Operation Center may serve as the point of network entry to enable secure connection to Morehead.
(5) Obtain ground station monitor data that provides information of the ground equipment operation and spacecraft signal conditions observed during the track, e.g., antenna pointing, received signal conditions, transmitted power and frequency. For Morehead, due to development constraints, the monitor data delivery is done manually after the pass if requested, rather than automatically in real-time during the track as with the DSN station.
(6) Interact with the DSN and Morehead operation teams during the track for necessary changes or progress updates via voice communications network.

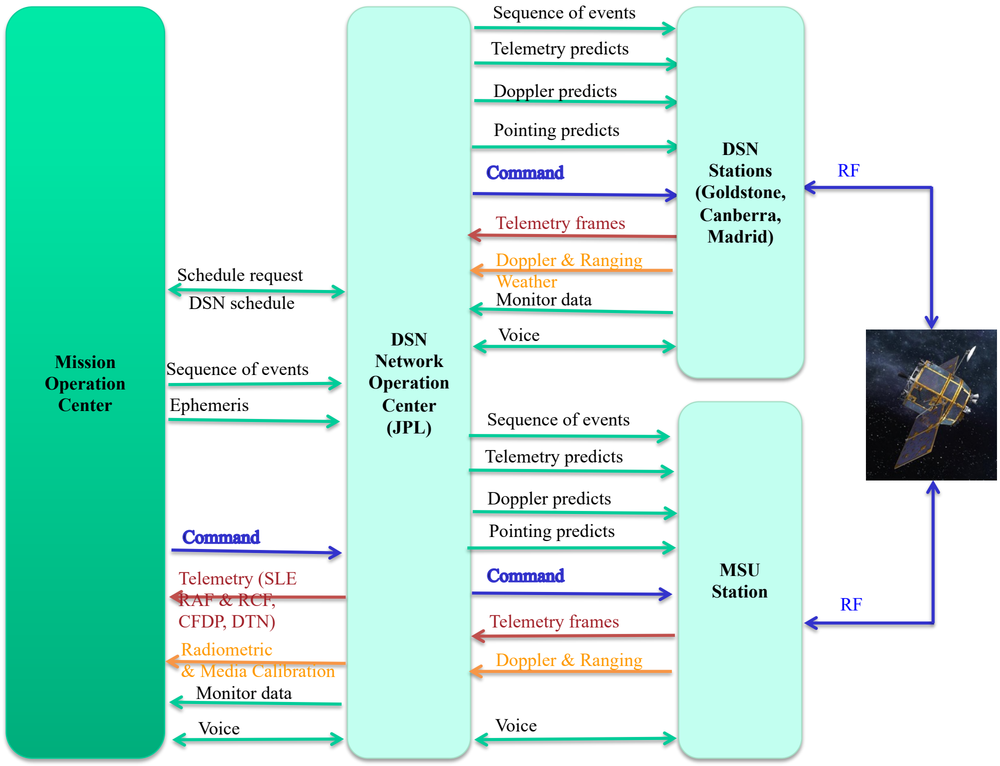

Fig. 1 Interfaces with Mission Users for both Morehead and DSN Stations

3. System Architecture

Figure 2 shows the architecture of the Morehead ground station DSS-17 [2]. The DSN Network Operation Center manages service requests from mission users and delivers telemetry and tracking data to mission users. DSS-17 is connected to the DSN Network Operation Center at JPL via the NASA Mission Backbone Network. This network connection provides security and redundancy required for mission operations

There are analog and digital portions of the system at Morehead station. The antenna, transmitter, uplink IF/RF upconverter, low-noise amplifier, downlink RF/IF downconverter and front-end station monitor control are developed by the Morehead implementation team and are site unique equipment. The Uplink and Downlink digital signal processing equipment that handle uplink signal generation (carrier, command and ranging data) and downlink signal demodulation/decoding, as well as doppler and ranging measurement, are the same equipment deployed at DSN stations. This enables the same data format with DSN stations. Data from Morehead are relayed to the DSN Network Operation Center and delivered to mission users. Telemetry data delivery complies with CCSDS protocol of Space Link Extension for Return All Frames (RAF) or Return Channel Frames (RCF), and CCSDS File Delivery Protocol (CFDP). Tracking data of Doppler and ranging are also delivered to the mission users via CCSDS standard Tracking Data Messages (TDM) or DSN-specific data format. Command data is sent from the MOC directly to the Uplink equipment at Morehead, using the CCSDS protocol of Space link extension for Forward Command Link Transmission Unit (CLTU).

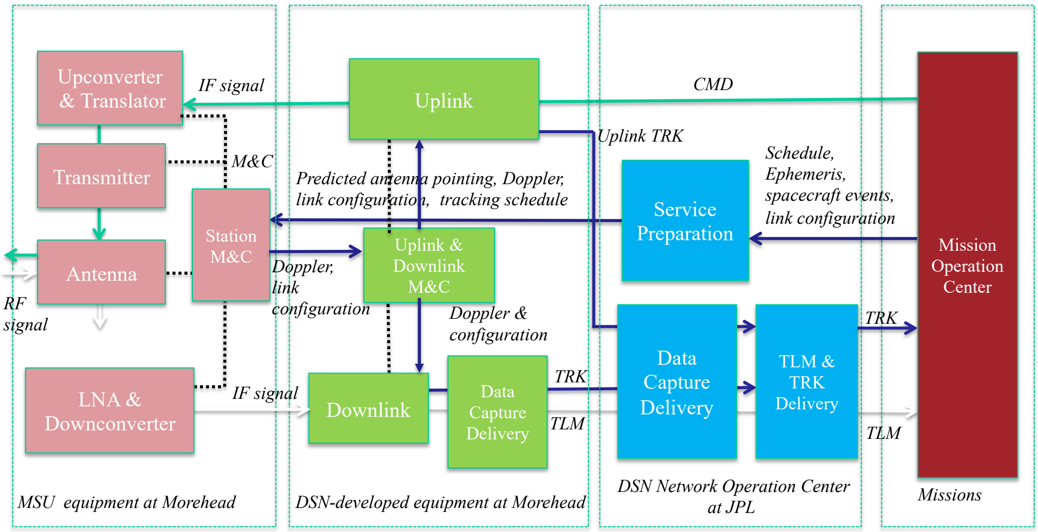

Fig. 2 Integrated system architecture of Morehead station and DSN infrastructure

The architecture at Morehead station also provides another path for mission support that does not utilize the DSN, as depicted in Figure 3. For commercial mission users, the functions of DSN-developed Uplink and Downlink are done by mission-user developed equipment. They would generate an uplink signal which is then interfaces directly with the Morehead Transmitter. On the downlink, the LNA or Downconverter output signal is routed to and processed by mission user-developed equipment. The Morehead station would be responsible for accurately pointing the antenna to spacecraft, transmitting the uplink signal and amplifying the received RF and downconverting to IF. This commercial user service is further discussed in Section 5 on Sustainability Model.

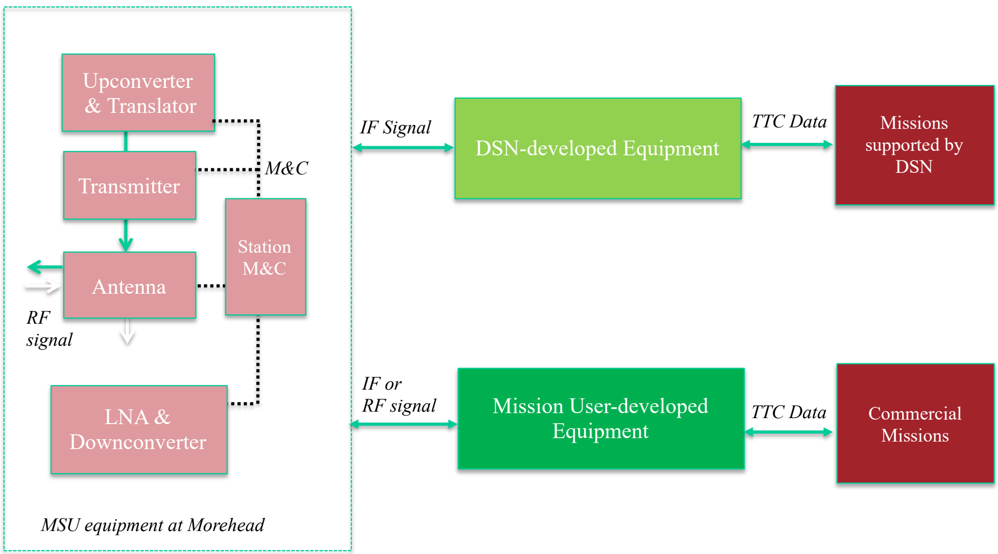

Fig. 3 Dual configurations of Morehead operations as a DSN-affiliated or independent station

4. **Low-Cost Development Model**

Several approaches are taken in building the Morehead station to minimize the development cost:

(1) In-house development as much as possible – Taking advantage of technical resource available within the University where staff and some RF components were available, Morehead takes charge of development of the antenna front-end equipment. Besides having lower labor cost, this approach also allows technical development activities and build up the RF expertise at Morehead. The knowledge gained in system development also makes the maintenance of equipment easier. One lesson learned is that the inhouse design needs to be well documented so that when there is personnel transition, especially on short notice, new team members would be able to pick up the knowledge required to maintain the equipment.

(2) Deferring capabilities that are not critical in face of limited funds– Certain capabilities that exists at DSN stations such as the ability to automate the configuration setup of equipment at the start of the tracking pass and changing the configuration during the pass in response to changes in the communications link would be desirable to have at Morehead. It would reduce the operator workload and enable delivering of ground station monitor data to mission users. However, due to funding limitation, this capability could not be made available. Instead, the Morehead team rely on manual process to configure the equipment, change the receiver and exciter configuration in response to mission sequence of events, and extract monitor data offline if requested by mission users.

(3) Leverage other test capabilities for mission ground data system (GDS) testing – The DSN has a test instrument that can emulate spacecraft downlink signal to support mission GDS testing before mission launch. This test instrument modulates the mission-provided telemetry data onto an RF signal that emulates the spacecraft downlink. In the absence of such a test equipment, the Morehead team relies on a commercial low-cost transceiver option to record and play back spacecraft signal. The transceiver would capture the spacecraft signal during DSN compatibility testing, or DSN-generated test signal during GDS test with DSN antennas and then play it back into Morehead system to support its mission GDS testing [3]. This was done for LunaH-Map, Lunar Flashlight, NEAScout and CuSP GDS testing at Morehead. For the Lunar IceCube, flight communications equipment or its equivalent was available at Morehead to support GDS testing.

5. Approaches for sustaining operations

The Morehead State University team is evolving a sustainability model to facilitate continued operations of the ground station. The station, being a university-owned and operated asset, has the capability to provide services for government (NASA) missions and private sector lunar missions. The station operates in two modes as a result: (1) DSN Mode and (2) Commercial Missions Mode.

(1) In DSN Mode, the station operates as NASA Deep Space Station 17 (DSS-17), utilizing an architecture comprised of COTS systems and systems developed in-house at MSU along with DSN instrumentation (Block 6 Exciter/Receiver). In DSN Mode, the station is connected to the NASA Mission Backbone and flows data to the DSN Network Operations Center as is typical of DSN stations.

(2) In Commercial Missions Mode, the station utilizes an architecture comprised of COTS systems and systems developed in-house at MSU along with receivers, modems and exciters provided by the mission. In this mode, the 21-m station utilizes a commercial network.

Having the flexibility to operate in these diverse modes, allows MSU to support a diverse range of missions. The MSU operations sustainability model is based on these diverse capabilities.

In DSN Mode, the underlying idea is for MSU to provide tracking and command services for NASA lunar smallsat missions to reduce loading on the DSN. Toward that end, NASA has supported MSU to provide tracking services for several of the lunar CubeSat missions including CAPSTONE (that is currently operating in lunar orbit) and several of the CubeSat missions that flew as secondary payloads on Artemis 1, including the CubeSat to Study Solar Particles (CuSP), LunaH-Map (HMAP), Lunar Flashlight (LFL), Lunar IceCube (MLIC), and Near Earth Asteroid Scout (NEAS). Table 1 shows DSS-17 support to these missions. These secondary payloads had limited success, likely owing to long storage times while the Space Launch System (SLS) was being prepared and owing to weather a hurricane on the launch pad at the Kennedy Space Center. However, DSS-17 was utilized to provide services for these missions (details shown in the table below), relieving the DSN from hundreds of hours of tracking time. Although the Artemis 1 interplanetary missions had limited success, tremendous lessons were learned and the viability of utilizing DSS-17 to reduce loading on the DSN by taking on lunar CubeSat missions was proven out.

Table 1 Artemis 1 Interplanetary CubeSats Supported by DSS-17

MISSION	DOWNLINK FREQUENCY	UPLINK FREQUENCY	NEAR EARTH vs. DEEP SPACE	DSS-17 SUPPORT
Lunar IceCube	X-band	X-band	Near Earth	Uplink, Downlink
LunaH-Map	X-band	X-band	Near Earth	Uplink, Downlink
Lunar Flashlight	X-band	X-band	Near Earth	Uplink, Downlink
NEAScout	X-band	X-band	Deep Space	Downlink
CuSP	X-band	X-band	Deep Space	Downlink

Note: Support to NEAScout and CuSP uplink is not available due to a restriction of transmission license in deep space band, for missions beyond 2 million km from Earth.

In Commercial Mission Mode, MSU provides telemetry, tracking and command services for a variety of missions ranging from lunar orbiters to lunar landers to interplanetary smallsats on their outbound trajectories. DSS-17 is particularly well-suited to provide services for lunar orbiting spacecraft. DSS-17 has provided consistent support for CAPSTONE (the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment) since its launch in 2022. CAPSTONE is a lunar orbiter that is validating the stability of a near rectilinear halo orbit (NRHO) planned for the Lunar Gateway space station. DSS-17 has provided over 600 hours of services for CAPSTONE, providing radiometric data for navigation purposes, returning data and telemetry and issuing commands to control the spacecraft.

Lunar landers represent a significant challenge for direct to Earth (DTE) communications. Ranging from limited transmission power and multi-path effects to potentially anomalous orientation upon landing, DTE communications from lunar landers has proved to require adaptable engineering. DSS-17 served as one of the primary ground stations on the Intuitive Machines Lunar Tracking Network (LTN), an ad hoc assembly of large aperture commercial ground stations, for both the IM-1 and IM-2 landers [4]. While both landers experienced landing anomalies and operated shorter than anticipated, tremendous lessons were learned and the use of DSS-17 was extremely successful. During the IM-2 mission, DSS-17 returned data from the spacecraft in lunar orbit at a rate of 2 Mbps. After adapting to an unfavorable orientation of the high gain antennas after landing, the IM team was able to utilize DSS-17, the DSN, Goonhilly, and the NRAO VLBA to return gigabytes of data from the lunar surface. A summary of the lunar missions supported by DSS-17 to date is provided in Table 2 below.

Table 2 Commercial Interplanetary Missions Supported by DSS-17

MISSION	TRACKING HOURS
CAPSTONE	640 Hours
IM-1	131 Hours
IM-2	110 Hours
Astroforge Odin	42 Hours

6. Conclusion

An economical and sustainable model for development and operations of the Morehead 21-m station as a DSN-affiliated as well as an independent station are presented. The flexibility of the station to be utilized by many users has demonstrated its success as a long-term operational antenna that can contribute greatly to NASA/DSN and space exploration endeavors.

Acknowledgements

The work described in the paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, and the Space Science Center at Morehead State University, under contract with the National Aeronautics and Space Administration. Initial funding for the upgrade project was provided by the NASA's Advanced Exploration Systems (AES).

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