A Low-Cost, Autonomous, Ground Station Operations Concept and Network Design for EUVE and Other Earth-Orbiting Satellites

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Abstract

The Extreme Ultraviolet Explorer (EUVE) satellite was designed to operate with the Tracking and Data Relay Satellite System (TDRSS) and Deep Space Network (DSN). NASA, the Jet Propulsion Laboratory and the Center for EUV Astrophysics have been evaluating a commercially available ground station already used for NASA's Low Earth Orbit (LEO) weather satellites. This ground station will be used in a network of unattended, autonomous ground stations for telemetry reception, processing, and routing of data over a commercial, secure data line. Plans call for EUVE to be the initial network user. This network will be designed to support many TDRSS/DSN compatible missions. It will open an era of commercial, low-cost, autonomous ground station networks. The network will be capable of supporting current and future NASA scientific missions, and NASA's LEO and geostationary weather satellites. Additionally, it could support future, commercial communication satellites in low, and possibly medium, Earth orbit. The combination of an autonomous ground station and an autonomous telemetry monitoring system will allow reduction in personnel. The EUVE Science Operations Center has already reduced console work from three shifts to one by use of autonomous telemetry monitoring software.

Keywords

Ground Station Network, Low-Earth Orbit Satellites, Commercial off-the-Shelf Technology.

Introduction

The Extreme Ultraviolet Explorer (EUVE) project is a NASA, Goddard Space Flight Center (GSFC) funded mission. The EUVE payload was designed and built at the University of California at Berkeley. EUVE launched on June 7, 1992, on a Delta II rocket with a mission to explore the universe at extreme ultraviolet (EUV) wavelengths (Bowyer & Malina 1991).*

The EUVE science payload is operated from the EUVE Science Operations Center (ESOC) at UC Berkeley's Center for EUV Astrophysics (CEA). The Flight Operations Team (FOT) at GSFC operates the Explorer Platform (EP) using resources and personnel from many departments. The ESOC at Berkeley is now manned only during daytime hours and relies on a newly developed autonomous telemetry monitoring system for off-shifts. The GSFC FOT currently staff the mission operations room 24 hours a day.

All communications between the EUVE/EP satellite and the ESOC and mission operations room at GSFC are routed through NASA's Tracking and Data Relay Satellite System (TDRSS**). The TDRSS services many users with diverse operational and communications requirements. The EUVE/EP shares TDRSS resources with other NASA programs including the Space Shuttle. When EUVE/EP data are received by TDRSS, they are relayed to GSFC via a complex communication path shown in Figure 1.

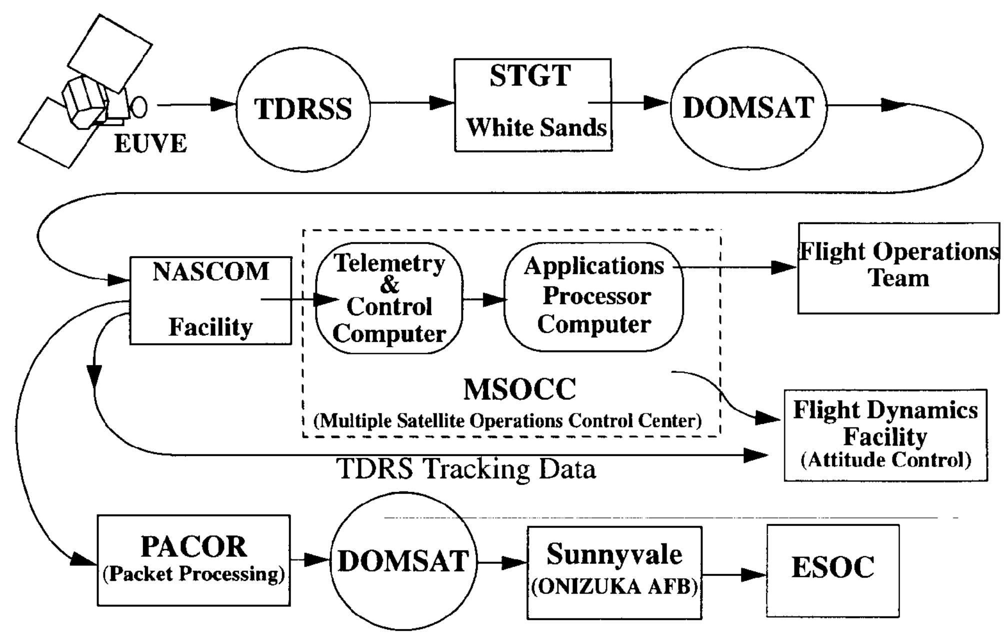

FIGURE 1. Current EUVE Telemetry Path

The Ground Station Network Operations Concept

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* For more information on the EUVE project and recent discoveries, visit the World Wide Web site for the Center for EUV Astrophysics at http:www.cea.berkeley.edu.

**TDRSS is a small constellation of TDRS communications devices that share the task of collecting and relaying data to missions in orbit.

The Ground Station Network Operations Concept

The EUVE project direct-to-ground objective is to monitor and control the EUVE/EP using a network of inexpensive, unmanned, commercially available, autonomous ground stations. These stations will receive EUVE/EP data transmissions directly from the satellite as it passes over each ground station. Demodulated telemetry will then be routed to CEA.

The commercial off-the-shelf (COTS) ground stations will be placed at sites around the globe for the reception and routing of data from the satellite. Satellite passes will be scheduled and tracked autonomously at each site based upon orbital elements obtained from sources such as the North American Air Defense. Preliminary data processing could begin at each ground station. Since only a small portion of each ground station's time is required to support EUVE/EP, it would be cost effective to share sites with other missions. Existing and future science missions currently under consideration for involvement in a LEO network include EUVE, FUSE, SAMPEX, and XTE.

Requirements for EUVE Coverage

When selecting ground station locations for EUVE/EP, a main objective will be to obtain the full amount of desired science data from EUVE/EP. Useful EUV data comes primarily from the night portion of each orbit. However, for the purpose of spacecraft engineering analysis, telemetry from all positions in the orbit is desired. The EUVE/EP communications and data handling (C&DH) subsystem is equipped with two tape recorders (TR). They record telemetry at 32\x11kbps for a maximum stored amount of 979.2 Mbits per recorder. However, only half of each recorder's data storage capacity (8.5 hours) remains because of two failures.

The EUVE/EP C&DH subsystem can transmit data to TDRSS or a ground station at the following data rates: 1 kbps, 32 kbps, 512 kbps, and 1024 kbps. Currently, real-time data are transmitted at 32\x11kbps. Data are stored on a tape recorder at the 32\x11kbps data rate. The data are played back and transmitted at either 512 kbps or 1024 kbps.

Table 1: Data Collection Scenarios

Data Collection Scenario	TR Playback Frequency (hours)	Data Quantity Collected	CEA: Payload Impact	GSFC: Spacecraft Impact
100% day 100% night	0.25	100%	No change from current operations	No change from current operations
100% day 100% night	0.125	100%	Increases anomaly resp. time to 8 hrs*	Increases anomaly resp. time to 8 hrs*
57% day 100% night	0.087	71%	Increases anomaly resp. time to 12 hrs*	Increases anom. resp. time to 12 hrs* Increases TR on/off cycles; Decreases TR dump cycles Decreases Telemetry data base
28% day 100% night	0.0625	52%	Increases anomaly resp. time to 16 hrs*	Increases anomaly resp. time to 16 hrs* Decreases Telemetry data base
0% day 100% night	0.042	33%	Increases anomaly resp. time to 24 hrs * No day data for anomaly resolution	Increases anomaly resp. time to 24 hrs * No day data for anomaly resolution Decreases Telemetry data base. Increases TR on/off cycling

Criteria for desirable EUVE/EP ground station locations are: long pass duration times, frequency of good contact durations, and minimal local obscura. Our studies show that many unacceptable passes may result from low antenna elevation or short contact duration or both, regardless of geographical location. The ground station antennae at a site must reach an elevation significantly above the horizon in order to minimize signal degradation from atmospheric conditions and physical obstructions. A "good" candidate site will have several passes per day with 5 to 10 minute pass durations of high (greater than 25) elevation.

Because of the tape recorder failures, an EUVE/EP ground station network design must be able to meet EUVE science data collection requirements for worst case operations. The actual amount of data recorded per day will vary. The following table provides the total number of minutes of contact time required per day for each of the available downlink data rates, assuming 12, 8, or 4 hours of stored data for transmission to the groundstation each day.

Table 2: Contact Time Required per Day for Downlink of Data

Data Transmission Rate	Contact Time per Day		
	12 hours of data	8 hours of data	4 hours of data
32 kbps	12 h	8 h	4 h
512 kbps	45 min	30 min	15 m
1024 kbps	22.5 min	15 min	7.5 min

Table 2 shows that to collect 8 hours of data per day, at a downlink rate of 32 kbps or lower, requires several hours of contact time per day with the ground stations. Daily contact periods of 8 hours or more are undesirable because of the large number of ground stations required (an estimated 10 receiving stations would be needed to achieve 8 hours of contiguous contact time with the EUVE/EP per day). Using a ground station network with on-board functioning tape recorders, it is preferable to downlink data at either the 512 kbps or the 1024 kbps rates to minimize the contact times with a ground station. A real-time downlink rate of 32 kbps will be used in the event all tape recorders fail.

Considerations for Ground Station Design

The ground station network should be designed so that it can easily support other NASA missions in addition to the EUVE/EP. Ideally, each ground station would be able to support a number of different NASA satellites in Earth orbit. From the results of early studies, a typical pass for a satellite such as EUVE over a favorably located ground station will have a duration of approximately 12 minutes. An operations concept that can yield the maximum time for data retrieval is to begin dumping the tape recorder as soon as signal lock is achieved. If the tape recorder has not completed the playback cycle in that period, the recorder must finish during contact with the next ground station in the network or the next pass with the same ground station. Since it is difficult to predict the lifetime of the tape recorders, the number and locations of ground stations in the network should be selected to provide nearly continuous real-time coverage. In the event that continuous real-time coverage is not possible, TDRSS could be used to supplement a ground station network.

The EUVE/EP is equipped with a low-gain, omni-directional antenna and a high-gain, directional dish antenna with a maximum data transfer rate of 1024 kbps. Once TDRS support is no longer necessary, use of the low-gain, omnidirectional antenna will begin because it provides broad coverage more suitable for satellite-to-ground station communications and will not exceed ground flux density requirements.

Preferred Ground station Locations For a Network

At the 512 kbps rate, data transfer requires approximately 30 minutes of good, contiguous periods of ground station contact. Although 30 minutes of good, contiguous periods of contact cannot be achieved from any of the sites evaluated, having the EUVE/EP pass over a ground station location for several consecutive orbits may allow sufficient time to downlink all of the stored tape recorder data. After these consecutive orbits, approximately 16 hours later, EUVE will pass over the ground station again for several consecutive orbits. To illustrate this, Table 3 displays starting times for each EUVE pass over the Honolulu, Hawaii, site evaluated over a 3-day period.

Table 3: EUVE Passes Over Honolulu, HI[a]

Date	Pass Start Time (GMT)	Pass Duration (mm:ss)	Time between Consecutive Passes
07/09/94	10:19:50	6:30	
	11:59:10	8:20	1:40:00
	13:40:20	7:40	2:21:10
	15:21:30	7:20	2:21:10
	17:02:00	8:10	2:21:10
	18:42:40	7:50	1:40:40
07/10/94	09:59:50	6:50	16:42:30
	11:39:20	8:20	2:20:10
	13:20:40	7:30	2:21:20
	15:01:40	7:30	2:21:00
	16:42:10	8:10	1:41:10
	18:23:00	7:20	2:21:30
07/11/94	9:39:40	7:10	16:02:40
	11:19:40	8:00	2:20:00
	13:00:40	7:30	2:21:00
	14:41:50	7:30	1:41:10
	16:22:20	8:00	2:21:10

[a] Data obtained from the SeaSpace Corporation's Terascan software.

Omitron (Douglas 1994) completed a study for NASA Headquarters to evaluate the feasibility of using candidate locations (see Table 4) as placement sites for ground stations in a LEO network. The selection of these locations was based upon the following factors: proximity to the equator; known, existing, ground station locations for other satellites; and previously acknowledged interest in locating a ground station at a particular site. Both Atlantic and Pacific locations were considered. Another important factor used in selecting locations in this study was the amount of telecommunication infrastructure already in place. Other site locations that have expressed interest include members of the Space Grant Consortium. A ground station at any of these universities will enhance the educational aspect of the direct-to-ground effort. To date, several universities have shown strong interest in this project including the University of Hawaii, University of San Diego, Western Kentucky University, and the University of Miami.

The potential exists to reduce the collection of continuous science data from 24 hours per day to only data from the spacecraft orbital night. This is about 33% of the EUVE/EP orbit and is equivalent to 35 minutes of each 95 minute orbit. In the event that only nighttime data are recorded, then a total of 8 hours of science data are recorded per day. This respecification means that without an opportunity to downlink the stored tape recorder data, up to 24 hours could pass before a tape recorder dump is necessary and all nighttime data could still be received and forwarded. At the highest downlink rate of 1024 kbps, only 15 minutes of playback time per day is required to downlink the data (see Table 2). In this operational scenario, one ground station located near the equator would be sufficient to receive all the science data for a 24 hour period. TDRSS would then be used only during ground station maintenance periods and spacecraft anomalies.

Table 4 lists pass durations and average, maximum elevation for candidate locations. It assumes 3 as the minimum elevation for an antenna.

Table 4: Visibility of EUVE from Selected Candidate Earth Station Locations

Location	Average Pass Duration(mm:ss)	Average Maximum Elevation(degrees)
Australia, Canberra	5:45	17.1
Spanish Territory, Canary Islands	6:20	12.08
American Virgin Islands	8:25	29.88
California, Berkeley (UCB)	7:31	13.97
California, Pasadena (NASA JPL)	7:28	20.08
California, San Diego (UCSD)	7:48	23.82
Texas, Clear Lake (NASA JSC)	09:19	30.46

California, San Diego (UCSD)	7:48	23.82
Florida, Miami	9:03	39.23
Hawaii, Mauna Kea (Keck Observatory)	8:51	37.75
Kentucky, Bowling Green (WKU)	7:20	15.49
Texas, Austin	08:26	36.16
Texas, Brownsville	09:40	47.0

Table 5: Summary of Orbitrack Results for 10 Degree Horizon

Locations (abbreviation)	Smallest Gap(min)	Largest Gap(min)	Total Contact Time(min)	Potential Data Transfer(MBits/s)	Average (b/s)
CI, AU, HI, SD CA, VI	2	442	1,426	41,777.34	60,842.67
HI, SD CA, VI	2	530	930	27,246.09	39,680.00
CI, HI, VI	4	442	1,019	29,853.52	43,477.33

Table 6: Summary of Orbitrack Results for a 5 Horizon

Locations (abbreviation)	Smallest Gap(min)	Largest Gap(min)	Total Contact Time(min)	Potential Data Transfer(MBits/s)	Average (b/s)
CI, AU, HI, SD CA	1	342	2,053	60,146.48	87,594.66
HI, SD CA, VI	1	431	1,326	38,847.66	56,576
CI, HI, VI	2	342	1,427	41,806.64	60,885.33

Legend: CI = Canary Islands, AU = Australia, HI = Hawaii, SD CA = San Diego, California, VI = Virgin Islands.

The LEO-D Test

The Jet Propulsion Laboratory (JPL) conducted a proof-of-concept test from July through December, 1994. The Low Earth Orbit Demonstration (LEO-D) project purchased a modified, commercial, ground station system from SeaSpace Corporation of San Diego in early 1994. The system was installed in June, 1994, on a mesa behind JPL. The LEO-D equipment consisted of an automated, turnkey, weather satellite terminal with COTS hardware upgrades for L & S-band signal reception, a programmable receiver, a SPARC workstation, COTS software, and network interface hardware.

The satellites chosen for the demonstration were agreed upon prior to the installation-EUVE and SAMPEX. EUVE is in a 28,500 km, inclined orbit, compatible with a potential Space Shuttle recovery mission. SAMPEX is in a 580 Km, 82, inclined orbit. Satellite downlink signal, modulation, and decommutation requirements are compatible with many NASA satellites.

During the test, the ground station received data on a regular basis from both SAMPEX (operated from the University of Maryland) and EUVE. Satellite contact times were automatically scheduled by the ground station software. Data collection and file transfers were autonomously performed. After SAMPEX and EUVE data were received, level-zero processing was done, and the data sets were automatically shipped to the appropriate University on a commercial, secure, network line.

Summary

The studies done by JPL, CEA, and Omitron show that use of COTS ground stations for collecting science data from LEO satellites would greatly reduce the cost of existing and future missions. The results of the LEO-D testing performed by JPL further support this thesis.

To achieve a data downlink using the smallest number of ground stations, the satellite will use multiple rates depending on on-board data storage devices. Each ground station needs to have the flexibility to receive data over a large bandwidth consistent with NASA's existing and future science, communications, and weather satellites. Lengths of pass durations and antennae elevations indicate that ground station locations near the equator are best suited for receiving data from low-inclination satellites such as EUVE/EP. Polar orbiting satellites would not have this requirement.

Several universities located at low latitudes have shown interest in maintaining a ground station for EUVE and other missions. It should be noted that ground station analysis results obtained from sources at GSFC (Douglas 1994) show that 100% of EUVE science data could be downlinked with four ground stations located in Hawaii, San Diego, Austin, and Miami. Using only two ground stations located in Hawaii and Miami, only approximately 68% of EUVE science data could be successfully downlinked. From the results of this study, it is recommended that a network consist of three ground stations initially, preferably at the University of Hawaii, the University of Miami, and the University of San Diego. This placement would provide coverage of the EUVE/EP from approximately 80 to 160 west longitude.

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