THE IMPLEMENTATION OF NASA's LOW EARTH ORBITER – TERMINAL AS AN AUTONOMOUS GROUND NETWORK ASSET

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ABSTRACT

As part of NASA's goal to reduce costs for satellite telemetry and command ground support, the ground network has installed two autonomous ground terminals known as Low Earth Orbiter – Terminal's, or LEO-T's. These systems are highly automated and were developed to prove the feasibility of supporting multi-mission satellites in a hands-off mode.

KEY WORDS

autonomous, EPOCH 2000, ground station, FUSE, IIRV, IONet, ISDN, LEO-T, NASA, SNOE, TCP/IP

NOMENCLATURE

ATSC	AlliedSignal Technical Services Corporation
DTI	Datron-Transco Incorporated
FTP	File Transfer Protocol
FUSE	Far Ultraviolet Spectroscopic Explorer
GSA	Ground System Administrator
IIRV	Improved Inter-Range Vector
IONet	IP Operational Network

ISDN	Integrated Services Digital Network
ISI	Integral Systems Incorporated
JPL	Jet Propulsion Laboratory
LEO-T	Low Earth Orbiter - Terminal
NASA	National Aeronautics and Space Administration
NORAD	North American Air Defense Command
SNOE	Student Nitric Oxide Explorer
SGP4	Simplified General Perturbations (Version 4)
STOL	Satellite Test and Operation Language
TCP/IP	Transfer Control Protocol/Internet Protocol
TLE	Two-Line Element
UDP	User Datagram Protocol
WFF	Wallops Flight Facility

INTRODUCTION

In response to a budgetary environment that required meeting customer requirements at a lower cost, NASA was motivated to develop a lower cost method of providing spacecraft telemetry and command services without compromising the level of support that had been expected in the past from their customers. NASA had made a decision to develop many smaller, cheaper satellites rather than a few large spacecraft as was done in the past. NASA was therefore being driven to provide more ground station capacity for spacecraft telemetry and command services with this decreasing budget trend. Another factor pushing NASA to develop alternative lower cost solutions were the many NASA sponsored university class missions that were being driven to provide their own spacecraft telemetry and command services due to the increasing load on the NASA ground network. NASA's solution for this ever increasing load and need was to use the existing large aperture systems to support those missions requiring that level of performance and to support the remainder of the missions with a smaller low-cost system that would require much less operations oversight and routine maintenance.

In 1994 at NASA's Jet Propulsion Laboratory (JPL), an initiative was started to develop a highly automated ground system that would drastically lower the cost of providing spacecraft telemetry and command services to many of NASA's customers. The intent was to develop a demonstration terminal and conduct tests with some of NASA's newest low earth orbiting spacecraft. This demonstration terminal developed at JPL provided NASA with the foundation of what was possible with the current technologies to provide a degree of automation currently unmatched for routine spacecraft support. After JPL had proven what NASA had envisioned could indeed become a reality, NASA tasked Goddard Space Flight Center's Wallops Flight Facility (WFF) in Virginia to commercially develop and implement a class of ground station known as the Low Earth Orbiter-Terminal (LEO-T).

The needs of the customer were very important to NASA and therefore a driver behind any design that was to be attempted. NASA introduced the concept to the many flight projects that had been baselined as possible customers for the system. NASA's then Office of Space Communications hosted a conference with many of the flight projects in attendance. The overall concept, the proposed system architecture, and the customer interfaces demonstrated were all presented at the conference. Other than a few minor enhancements and changes to better meet support needs, the flight project customers were pleased with the new services NASA was intending to develop and provide.

The development team located at Wallops Flight Facility then began the task of generating a specification that included all envisioned customer needs and interfaces. In March 1996, NASA released a Request for Procurement for the LEO-T. The bid was awarded to AlliedSignal Technical Services Corporation (ATSC) in June 1996. The ATSC team consisted of Datron-Transco Incorporated (DTI) for the antenna subsystem, and Integral Systems Incorporated for the control and automation subsystem.

IMPLEMENTED LEO-T DESCRIPTION AND CAPABILITIES

The LEO-T antenna system is a fully autonomous unstaffed system that can operate without the existing NASA network operations support infrastructure. The LEO-T provides a low-cost, reliable space communications capability to the expanding number of low-earth orbiting missions. The system is also fostering developments that improve cost-effectiveness of autonomous-class capabilities for both NASA and commercial space communications use.

At this time, there are three LEO-T systems installed. The systems are located at the University of Puerto Rico in Mayaguez; the Poker Flat Research Range near Fairbanks, Alaska; and NASA's Wallops Flight Facility in Virginia. The installed systems include the 5-meter antenna subsystem, a radome to protect the antenna subsystem, and two racks of support electronics that provide the full capabilities of the system.

The system in Puerto Rico was installed to support the FUSE spacecraft. The first mission to officially use the other LEO-T systems in Alaska and Virginia is the SNOE spacecraft being managed by the University of Colorado. Additional spacecraft are being tested at this time and a number of small "explorer-class" missions are expected to be large users of these systems in the coming year.

Future development work on the LEO-T will include adding two-way Doppler measurement capability. This added feature will increase the LEO-T mission support list even further.

The key characteristics of the LEO-T include:

System
Autonomous, multi-mission tracking system utilizing high level of COTS equipment
5 or 3 meter program track antenna housed in 28 foot diameter sandwich type radome
TCP/IP or UDP/IP used for all command, telemetry, and administrative data transfers
X-windows interface for scheduling and administrative functions
X-windows interface for monitor and control
Automated system diagnostic tests can be initiated locally and remotely
Y2K Certified
Downlink
2200 to 2300 MHz
Antenna option for X-Band receive
G/T of 17 dB/K (5 m) and 12 dB/K (3 m)
Maximum rates of 4 Mbits/sec (8 Msymbols/sec)
Second channel subcarrier support
Forward Error Correction and Reed-Solomon Symbol Correction
Real time telemetry data transfer limited to user data circuit bandwidth
CCSDS virtual channel stripping
System generates composite data files which are available for post-pass FTP
Uplink
2025 to 2120 MHz
EIRP of 89 dBm (5 m) and 84 dBm (3m)
Real time throughput commanding
Store and forward command capability utilizing COP-1 verification

LEO-T NETWORK COMMUNICATIONS ARCHITECTURE

The LEO-T utilizes a 10Base-T Ethernet interface for connectivity to the outside world. All telemetry, command, and administrative data are transferred using TCP or UDP. The LEO-T’s at WFF and Alaska are connected to the NASA IONet wide area network centered at Goddard Space Flight Center in Greenbelt, MD. Connectivity between the tracking sites and Greenbelt is via commercially available T1 communication circuits. Users can access the LEO-T's by connecting directly to the IONet or by externally connecting to the IONet through a gateway using various services such as ISDN. A representative architecture of the NASA communications network is shown below in Figure 2.

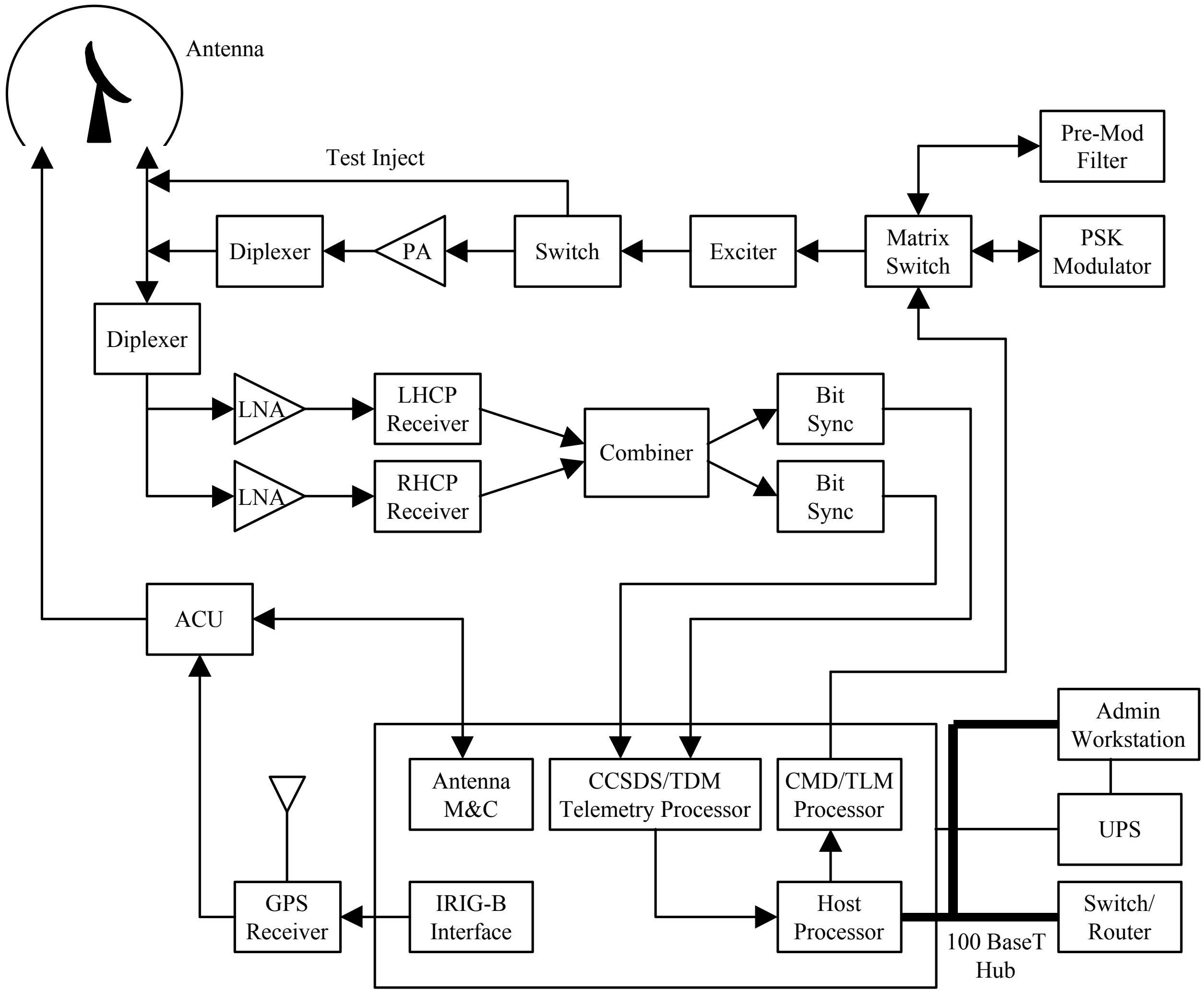

Figure 1: LEO-T Architecture

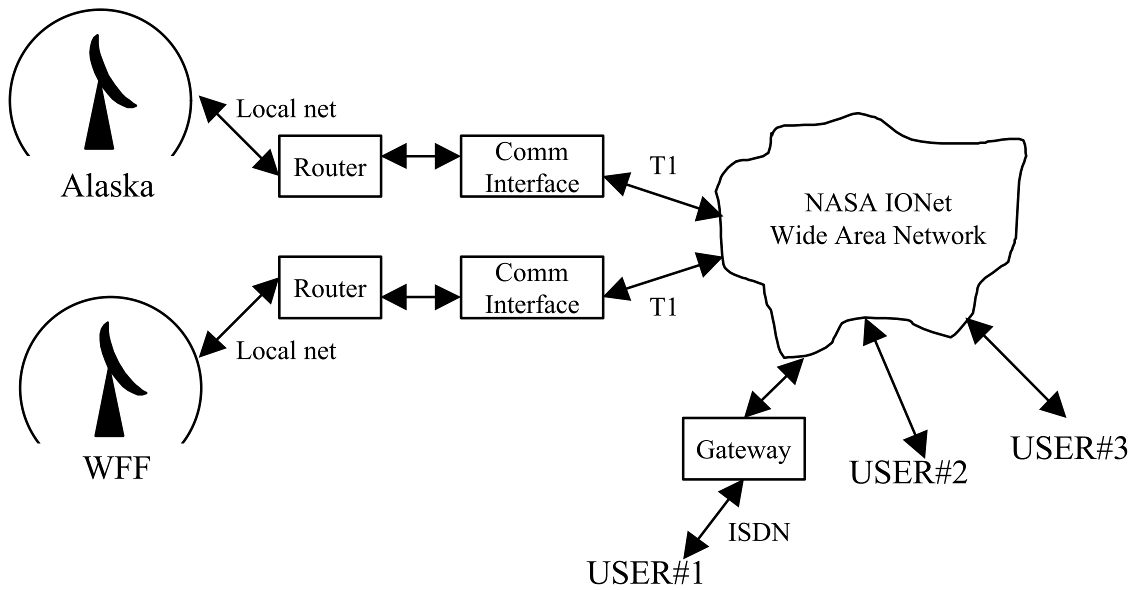

Figure 2: NASA LEO-T Communications Architecture

LEO-T OPERATIONS

System Schedule

The LEO-T operates in hands-off mode during routine operational periods. System events are completely schedule driven. The system schedule runs seven days at a time, Monday through Sunday. This weekly schedule is generated at GMT midnight on the proceeding Thursday.

The schedule is generated based upon pass requests submitted by each user. Prior to the Thursday schedule generation time, each user submits requested passes for the following week. Pass requests are submitted via the LEO-T X-window administrative display. Through this interface a user can either download a schedule request file or the user can select requested passes from a candidate pass list box.

At the schedule generation time the LEO-T generates a conflict free schedule for the following week based on a simple priority method. Each mission is assigned a priority on a system. Passes are scheduled as follows. The highest priority mission receives all passes requested. The second priority mission receives all passes requested that do not conflict with the highest priority mission. This is continued for each mission priority, resulting in a conflict free schedule.

Once the weekly schedule is generated, users can log into the system through the X-window administrative screen and add or delete single passes as desired. Users are only allowed to delete their own satellite passes. All users can add passes on a first come first serve basis if time is available. Partial passes can also be schedule if there is a potential conflict. It should be noted that system operators with administrative access have the ability to add and delete passes for any mission at any time. System access levels will be addressed later.

An organization operating LEO-T's can bypass this user scheduling method if desired. In many cases a service provider may find it more efficient to use a central scheduling office that takes customer requests and generates conflict free schedules for a series of LEO-T's. In this mode, one schedule request file can be downloaded to a LEO-T from the scheduling office with passes for all missions being supported. The system will use this file to generate the weekly schedule.

Once a schedule is in place and the system is on-line, three types of events are initiated according to the schedule: acquisition data retrieval, file maintenance, and pass events.

Acquisition Data

The LEO-T automatically acts as an FTP client and retrieves acquisition data files once a day for each satellite being supported by the system. The number of retrieval times per day is configurable. Files retrieved contain either NORAD two line elements (TLE's) or NASA Improved Inter-Range Vectors (IIRV's). Each mission is configured to use one or the other.

After the satellite acquisition data files are retrieved, predicted view times are generated for the week and IIRV's are converted to TLE's. The predicted view times are used for schedule generation, and the TLE's are downloaded to the antenna controller pre-pass. The antenna controller contains a SGP4 propagator used to generate pointing angles during a pass.

File Maintenance

System file cleanup and management is handled via the UNIX cron utility. Old schedules, telemetry files, pass log files, and stored command files are automatically deleted on a routine basis.

Pass Events

Pass events are started at the appropriate time according to the system schedule. The system maintains a standby condition until this time arrives. At this point, the system initiates the following automated pass sequence:

T-3 minutes
Pass start begins. Pass log file is opened. System executes internal bit error rate test. Results are posted in pass log file.

T- 1 minute
Telemetry and station status TCP/IP socket connections (or UDP transfer) initiated by LEO-T. Status packets are transferred once every 10 seconds for duration of pass.

T- 30 seconds
Uplink acquisition begins. The uplink transmitter is turned on and the un-modulated carrier begins sweeping. The antenna maintains elevation pointing at the masking point until the predicted elevation exceeds mask.

Acquisition of Signal (AOS)
Once the downlink is acquired, the system begins processing telemetry frames. Virtual channel frames designated for real time transfer are stripped and forwarded to the user. All frames are written to file. The uplink acquisition is completed when spacecraft lock is detected. Lock can be detected by monitoring the CCSDS Command Link Control Word (CLCW) radio frequency (RF) lock status in the telemetry frames or by monitoring the downlink sweep for coherency with the uplink sweep. Once sweep is terminated, command modulation is turned on, and the LEO-T system initiates the TCP/IP command socket connection. Real time commands can now be received and forwarded to the spacecraft. If the command portion of the pass is configured “store and forward”, commands will be retrieved from file and sent to the spacecraft at the transmit time associated with each command.

End of Pass
The uplink is turned off when elevation goes below masking and the antenna returns to stow. Real time TCP/IP sockets are closed at this time.

Post Pass
The LEO-T commences FTP transfer of telemetry data files to the user. Data can be stored as one composite file or as separate virtual channel files. Virtual Channel files can be assigned priority to control the order in which files are transferred. Since the FTP function is handled as a separate process, another pass can commence while the FTP continues without impact to the real time support.

SYSTEM MONITOR AND CONTROL FEATURES

The LEO-T system can be monitored and controlled locally as well as remotely. Monitor and control features, as well as system administrative functions, are accessed via X-displays. All users are allowed access to administrative functions, but only operators with ground system administrative (GSA) access have full access to all monitor and control features, as well as the administrative functions.

General User Access
General users have access to administrative functions and a limited amount of system control. The administrative functions include schedule display and submittal, and log file display and retrieval. A general user is provided with several control features that are enabled when that user's pass is in progress. The control features include uplink re-sweep, terminate uplink acquisition sweep, uplink off, and pass terminate.

GSA Access
An operator logged in as GSA has access to all administrative functions listed above as well as access to database configuration, automated system tests, and monitor and control. The additional features are also accessed through the main LEO-T system display.

Database Configuration
For each mission, one or more pass configurations are necessary. The LEO-T utilizes an Oracle database for managing system and mission configurations. Pass configurations are generated and edited via GUI windows by the spacecraft user.

Automated System Tests
A GSA user can initiate several automated system tests. These tests include G/T measurements, servo tests, and the antenna North alignment procedure.

Monitor and Control
The LEO-T monitor and control features were implemented with ISI's EPOCH 2000 software product. EPOCH 2000 is generally used for satellite control, but was adapted to controlling ground system equipment in the LEO-T. Many automated events in the LEO-T are executed using Satellite Test and Operation Language (STOL) procedures. This built in flexibility allows a GSA user to modify certain pass events if required. Procedures can also be generated for system and network testing. An EPOCH 2000 X-display is used for initiating and editing any STOL procedures. This screen provides the capability to display all parameters, or globals, that the system utilizes. The GSA user can configure multiple windows to display any globals desired, generally with one window for each subsystem. The window configurations can be stored and displayed as necessary.

LEO-T COSTS

The autonomous nature of the LEO-T has allowed NASA to lower the cost per pass for satellites that can be supported by the system. This section defines the current cost breakdown associated with using the LEO-T for support within the NASA ground-tracking network.

The total cost to purchase a full S-Band uplink and downlink system with second channel subcarrier support is approximately $1.5M. Spare equipment costs are approximately $300K per system. Routine maintenance and system repairs require approximately 1/3 of a man-year for a qualified field engineer and some expenditure associated with shipping. This cost is approximately $26K per year for the labor and shipping to support this task. Infrastructure costs include system installation and yearly utilities. Installation is a one-time cost and can cost anywhere from $50K to $100K depending on the location. Annual utility costs are averaging $15K. Administrative costs such as scheduling and logistics are averaging $15K annually. As a baseline, these costs will be spread out over 5 years. Therefore, the total cost for LEO-T operations over this 5-year period is:

System Cost	$ 1500 K
Spares	$ 300 K
Maintenance/Repair Labor	$ 130 K (5 years @ $26K includes shipping)
Installation	$ 100 K (worst case)
Utilities	$ 75 K (5 years @ $15K)
Administration	$ 75 K (5 years @ $15K)
Total	$ 2180 K

Naturally, the more passes supported by a single system, the lower overall cost per pass. Using a polar site as an example, it would not be unreasonable to expect that a system will support 12 passes a day at a minimum. Over the course of five years at this loading level, a LEO-T will support approximately 21,900 passes. Dividing the total costs over this time by the total number of passes results in an approximate cost of $100 per pass. It should be noted that this cost does not include the cost of communications between the LEO-T and the end users. Communications costs vary greatly depending on the location of the ground station and the location of the end users. As a baseline, a T1 costs $40K per month from Alaska to Maryland. If communication costs are passed on to the user using the method above, an additional $110 per pass would need to be added to passes supported at this polar site. This communications costs will be zero if the tracking system and the user are co-located and the communications costs will be greatly reduced if the LEO-T and the user are both located in the continental United States. Not all users will be able to fund a system of their own and some may require a number of contacts from a polar site. In this instance, a new mission may want to utilize the NASA LEO-T systems rather than purchasing a new system. Again, these costs should be used as a reference only, and are estimated costs based on the current operating environment.

CONCLUSION

The LEO-T's have been operational since January 1999. During this period, NASA has been able to assess the reliability of the systems. The hardware that is more susceptible to failure has been identified to improve the sparing philosophy. Software issues identified early in the development phase have been identified and corrected. At this time, the reliability of the system is above 95%. The operational cost savings NASA anticipated by supporting the implementation of an autonomous ground station of this complexity has proven to be a complete success.