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EFFICIENT MISSION CONTROL FOR THE 48-SATELLITE GLOBALSTAR CONSTELLATION

by

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ABSTRACT

The Globalstar system is being developed by Globalstar, Limited Partnership and will utilize 48 satellites in low earth orbit (See Figure 1) to create a world-wide mobile communications system consistent with Vice President Gore's vision of a Global Information Infrastructure. As a large long-term commercial system developed by a newly formed organization, Globalstar provides an excellent opportunity to explore innovative solutions for highly efficient satellite command and control. Design and operational concepts being developed are unencumbered by existing physical and organizational infrastructures. This program really is "starting with a clean sheet of paper."

Globalstar operations challenges can appear enormous. Clearly, assigning even a single person around the clock to monitor and control each satellite is excessive for Globalstar (it would require a staff of 200!). Even with only a single contact per orbit per satellite, data acquisitions will start or stop every 45 seconds! Although essentially identical, over time the satellites will develop their own "personalities" and will require different data calibrations and levels of support.

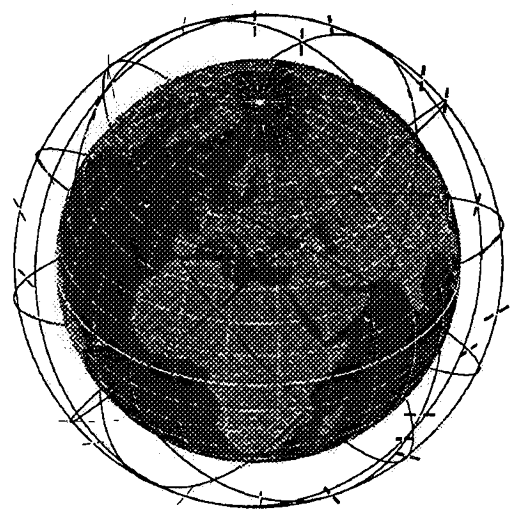

Figure 1: **Globalstar Constellation**

This paper discusses the Globalstar system and challenges and presents engineering concepts, system design decisions, and operations concepts which address the combined needs and concerns of satellite, ground system, and operations teams. Lessons from past missions have been applied, organizational barriers broken, partnerships formed across the mission segments, and new operations concepts developed for satellite constellation management. Control center requirements were then developed from the operations concepts.

This paper concludes by summarizing the applicability of these engineering processes and concepts to future missions of different magnitudes.

BACKGROUND

The growth in demand for telecommunications services over the last 20 years has been phenomenal. The projected growth over the next 20 years is expected to be even more dramatic.

Cellular phone systems are spreading across many parts of the world and, in some areas, are the primary mode of phone communications. Traditional cellular systems, however, may not be cost-effective in areas of low population density, very rugged terrain, or limited infrastructure.

Satellite-based systems now developing will bring affordable cellular-type voice and data communications to all regions of the world. A constellation of satellites can cover the globe with a network of moving cell sites. Ground-based systems coordinate handoffs between these moving cells in a manner similar to how handoffs are now coordinated when a vehicle moves between ground-based cell sites.

By using satellites, coverage is provided over most of the earth's surface. By using low earth orbit (LEO) satellites instead of geosynchronous satellites, time delays for the transmission to/from the satellites become imperceptible and power requirements are reduced to the point that hand-held phones can be developed.

The Globalstar system will utilize 48 satellites organized in eight planes of six satellites each. Eight additional satellites will be placed in phasing orbits as spares. The satellites will each be at an altitude of approximately 1400 kilometers in circular orbits inclined at 52 degrees. This orbit selection concentrates coverage in the middle, most populated latitudes, thereby increasing the level of overlapping coverage in order to expand system capacity in those regions and to strengthen system robustness. Should a satellite be lost, there is still total coverage over most regions.

Voice and low-rate data traffic will be routed from hand-held phones through one or more passing satellites and then to ground-based gateways. The gateways will switch the calls into existing public and private phone system networks (Figure 2). With this approach, the Globalstar system takes maximum advantage of existing switching systems, networks, customer bases, and billing systems. In addition to voice communications, the Globalstar system will provide position determination, paging, and messaging services.

The design and development of the Globalstar system is well underway, with satellite launches to begin in 1997 and the full constellation to be in place by the end of 1998. Loral AeroSys is under contract to develop the satellite operations control centers (SOCCs) and to provide operations support. Other contracts are in place for space segment development, for gateways and their control systems, and for the Globalstar phone units.

COOPERATIVE ENGINEERING DEVELOPMENT APPROACH

Efficient control of the Globalstar satellite constellation requires innovations beginning with the system definition and extending through to operations concepts and system design.

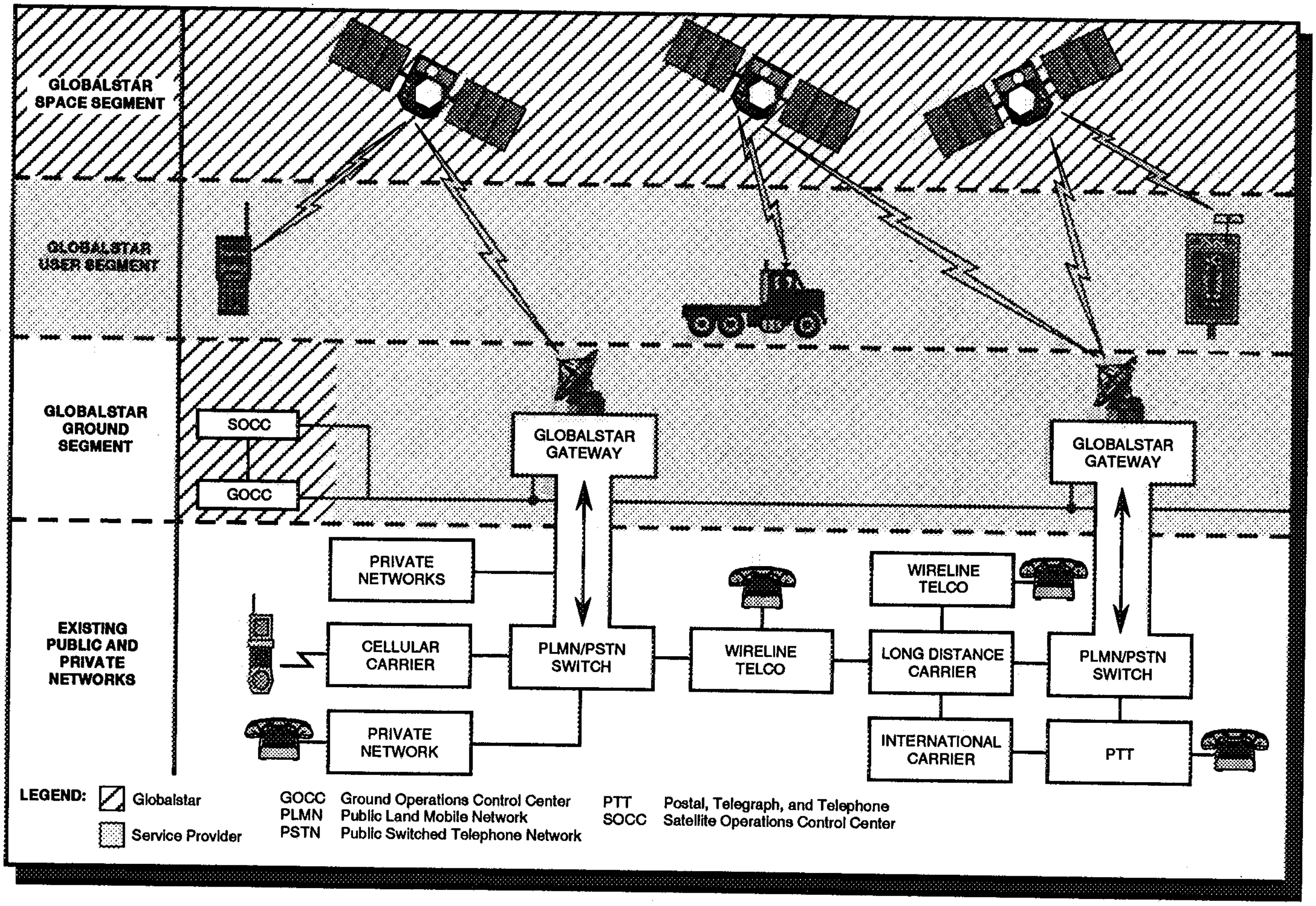

Figure 2: **Globalstar System Configuration**

In many traditional systems, a satellite is designed and specs are then given to the ground system developer who, under a different contract, builds a control center and provides it to the operations contractor to determine how to use it for a satellite they had only limited prior knowledge of. Globalstar, however, is being developed as a joint effort between system level, satellite, ground, and operations teams. A "trusted contractor" approach is employed where each participant is looked to as the expert in a particular field. In evolving this approach, Loral altered some of the traditional customer-contractor process flows while maintaining the necessary levels of progress oversight. Through working groups, relationships established between contractors, and other formal and informal concepts developed by Loral and the Globalstar, LP contractors, a total system concept has evolved and a WIN-WIN mentality has developed.

One example of the joint engineering approach is demonstrated in how the telemetry formats were designed. The Loral ground segment development personnel applied "lessons learned" with over 30 satellite systems to develop a list of telemetry stream characteristics of past systems which increased system complexity or were found to be of little use. In some cases the satellite manufacturer thought they had been "adding a feature" and in others the ground complexity was matched by a spacecraft complexity and both could be eliminated. The operations team is involved in specifying the resolution needed for specific on-board parameters and in defining the sample rate for the parameters. In some cases, the operations team has influenced the quantity, location, and types of on-board sensors. Spreadsheets and a common data base agreed to by all contractors allow for convenient information exchange. On-board data reduction replaces engineering tape recorders and allows graphs of a full orbit's data to be generated within seconds of the start of a new contact. All-in-all, the system cost and complexities have been reduced, more capabilities have been designed into the system, and the operations team will be provided access to telemetry data which best meets their defined needs.

A series of similar engineering efforts have been performed in the areas of ground system antenna site design, command formats, onboard autonomy, orbit determination approaches, and in a series of very specific spacecraft configuration areas. Evolving design decisions are incorporated into the operations concepts only after possible impacts to other areas are addressed.

In all cases, the concepts for operations are determined as a joint effort between the ground system developers and the operations personnel. In many cases, the satellite team is consulted to validate assumptions and to critique ideas. The end-goal of the effort is to meet all system objectives while limiting both the development and the lifecycle operational costs. With Globalstar, these costs play a critical role in determining the overall profitability of the enterprise.

OPERATIONS STRATEGIES

A set of strategies and plans for providing efficient management of the constellation have evolved along with the detailed operations concepts. Detailed SOCC requirements were developed from these ideas. Collectively, the strategies characterize the uniqueness of the Globalstar's efficient mission operations approach:

1. Process only the data needed. Through satellite autonomy and innovative data handling techniques, the nominal anticipated real-time monitoring and control period per satellite has been reduced to once per orbit, or about 10 minutes out of every 114 minutes. Data for other viewable portions of the orbit is stored at the remote ground stations and only processed if a need arises, much like a flight recorder on an airliner. If no problems are encountered, the remote site data is deleted after several days without ever being transferred to the SOCC.

2. Concentrate on the satellites with problems. Automated software monitoring of the satellite subsystems will allow some satellite contacts to occur without any human monitoring. All data streams received will be monitored by the software and only selected contacts will be monitored by the operations staff. Monitoring will take place at the parameter, satellite subsystem, and full satellite evaluation levels. The operations team will be able to define the evaluation criteria and to regularly update the checks performed to reflect differences between satellites and the increase understanding of the satellites' performance characteristics. This level of automation will be used to reduce the burden on the operations personnel for monitoring of healthy satellites and will allow additional time for working with satellites requiring special attention. The automated capability will be controlled so that every satellite is still observed at a minimal rate. The actual observation level for monitoring the constellation can be throttled based on factors such as problem histories, learning curves, constellation size, and even operation shifts.

3. *Make the best of the "few minutes per orbit" contact.* The objective is to utilize the limited real-time contact data to the fullest extent possible and to minimize the off-line analysis efforts required for other time periods. To orient the operator regarding the next pass, a contact log report will be generated indicating the times of the contact, the planned commanding activity summary, and any outstanding issues to be closely monitored. This report is updated with actual data throughout the pass and goes to the master pass log at the end of the pass. Automated procedures will allow planned operational steps to be executed without intervention. The use of on-board telemetry reduction allows for critical parameters to be collected at commandable intervals and downlinked as a data set during the pass. This information, which may cover an extended time period, is immediately viewable as plots and reports on the user's screen. With these plots, the user can rapidly assess the performance of parameters of interest over the entire previous orbit or, for example, during the critical seconds of a thruster firing. If necessary, immediate remedial action can be initiated should the stored data confirm a suspected anomaly.

4. *Take advantage of the large number of satellites.* Management of 56 satellites should not require 56 times the effort of managing a single satellite. There are several areas in which the large number of satellites is actually an advantage. A new method of looking for possible problems is to plot the data from many satellites on top of each other (aligned for equator crossing, time of day, land mass location, etc.) and to look for outliers. In effect, there are 55 control satellites for each satellite being evaluated. Additionally, theories regarding environmental factors can quickly be tested by looking for common reactions across multiple satellites. Having many satellites will facilitate the establishment of an anomaly resolution data base which can be searched by satellite or component. Procedures developed through lengthy analysis can often be applied to other satellites which experience similar problems at a later time and some common problems can be corrected on the ground prior to future launches.

5. *Monitor more than one satellite at a time.* Operations personnel will be able to monitor up to 6 satellites per workposition. With the concepts of multiple satellite monitoring, efficient display of information is crucial. A number of innovative displays have been developed to support constellation management. Map-based displays annotated with satellite status information create a high level system display, with satellite icon selection available to go to detailed information levels. Additional table-based displays support the monitoring of small groups of satellites and detailed text and graphical displays are used at the individual satellite level. Users will be able to tailor their screen definitions to best match their responsibilities and work approach.

6. *Automate the system configuration.* One contact per orbit equates to about 13 contacts per day per satellite, and about 700 contacts per day for the entire constellation. The total system is data driven and automatically reconfigured. Remote sites process all data received and log it to local disks or send it to the SOCC as directed in established setup tables.

Within the SOCC, the allocation of satellites to user workpositions and the configuration of the system to support the data streams will be automated. Operators will use generic terms to specify what satellites they wish to monitor. One operator may want to watch all satellites for which commanding is planned, while another may only want to watch satellites for which critical parameters are found to be out of limits. A wide variety of selection criteria have been identified which, together, can support a wide range of operations concepts.

7. *Manage for the mission lifetime*. The true goal of the operations team is to maximize the amount of time during which each satellite carries revenue bearing communications traffic. Many steps are in place to make the day-to-day operations efficient. The operations team will also work to extend the mission life of the system and the individual satellites. An on-line performance data base is maintained for the life of each satellite, beginning with assembly line testing results and calibrations. The anomaly history data base will allow problems to be tracked against time. Operational workarounds may be found to extend component life on many satellites based on information gathered from a few. For Globalstar, data exchanges between the satellite operations centers and the center which manages the phone traffic level and quality will allow for the development of joint operations procedures to maximize revenues and extend mission life.

CONTROL AND MONITORING OF 56 SATELLITES

Including on-orbit spares, the Globalstar operations team will be controlling 56 satellites from a single control center. As shown in Figure 3, the actual number of satellites normally viewed at a single time is considerably less. The level of satellite autonomy reduces the amount of time each satellite must be observed. On-board data storage allows for collection of critical performance data over the entire orbit. A distributed flight recorder concept, implemented across the network of ground stations, provides a data resource should problems be identified. Automation within the control center reduces the burden on the flight operations team and allows some contacts to be monitored only by the software. Collectively, these strategies allow a very small operations team to efficiently control and monitor the entire constellation.

As many as 12 satellites will be dispensed from a single launch vehicle. The system is sized to accommodate the high level of monitoring of each satellite during launch in addition to the routine operations which must continue. Anomaly investigation and resolution, orbit maneuvers, and infrequent large software and data loads to the satellites also require additional support. Operations personnel have been involved in sizing these efforts, determining the number of workpositions required, and supporting the facility design to best accommodate the variations expected in support requirements.

CONCLUSIONS AND APPLICABILITY TO OTHER MISSIONS

Efficient mission control is not just an operations issue - it must be designed into the satellite and ground system from the beginning.

Cooperative processes between contractors during the early concurrent engineering phase of system-level design can provide significant payoffs in terms of system capability and implementation and operations costs. The processes developed by the Globalstar team, involving multiple contractors around the world, have proven extremely successful.

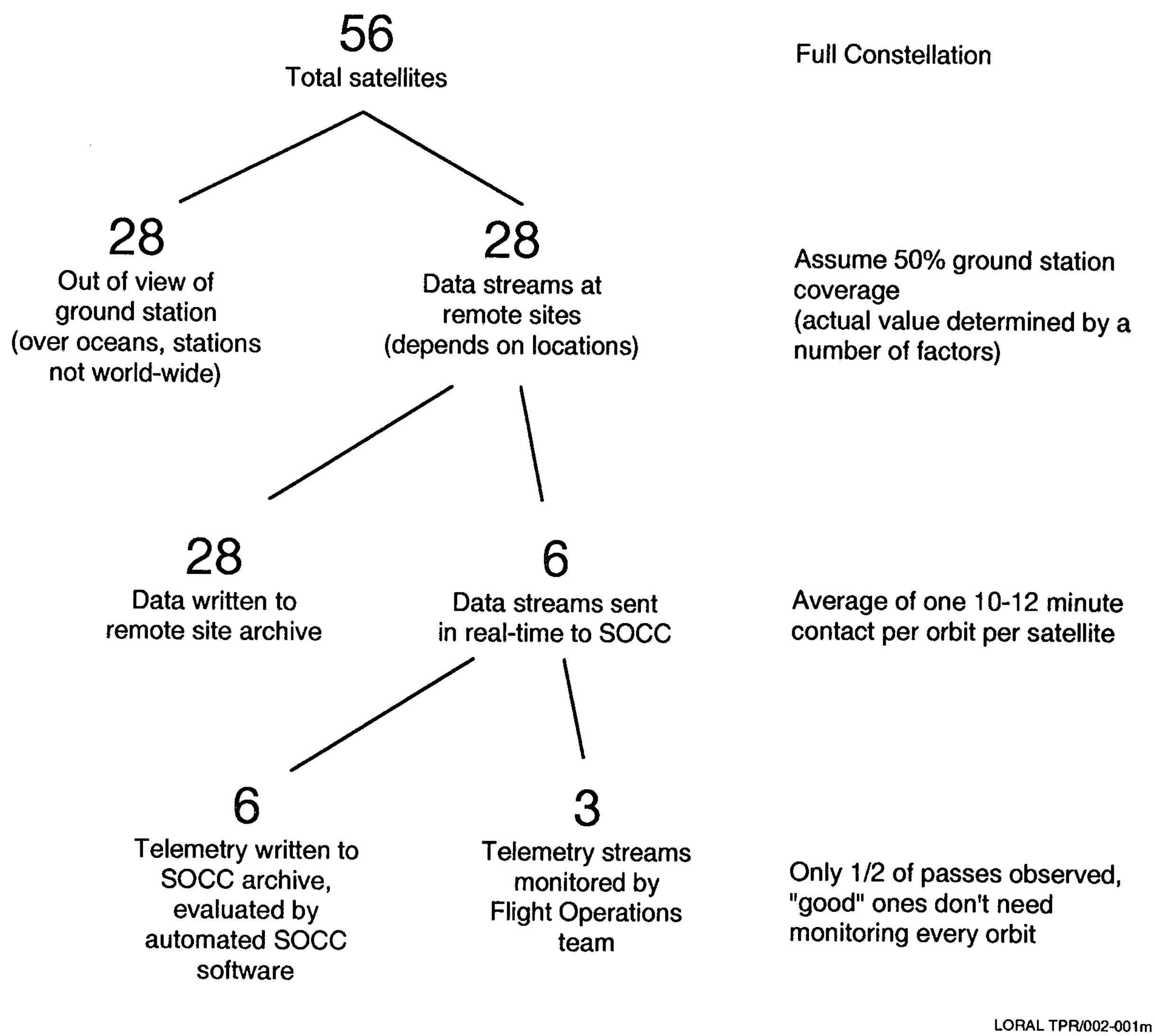

Figure 3: **Globalstar "Point in Time" Operations**

Process, technical, and "lessons learned" exchanges between government agencies and the private sector benefits all. In the case of the Globalstar mission, NASA lessons learned have been studied and mature operations concepts have been adapted and combined with new ideas to create the innovative approaches necessary to efficiently manage a very large satellite constellation.

Problem solving approaches and solutions will obviously vary depending on the application. The specific strategies developed for Globalstar help the overall system work effectively, and may be applicable to other systems. What is clearly applicable from the Globalstar effort is the understanding that new organizational and engineering approaches can lead to tremendous benefits.

The processes of trusted contractors, cooperative concurrent engineering across development segments, and a cross-contractor team approach, applied by a set of organizations with a broad base of disciplined engineering skills will lead to systems which are better engineered to meet the combined objectives of the mission and the individual goals of the supporting teams.

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