

## PORTABLE END-TO-END GROUND SYSTEM FOR LOW-COST MISSION SUPPORT

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### ABSTRACT

*This paper presents a revolutionary architecture of the end-to-end ground system to reduce overall mission support costs. The present ground system of the Jet Propulsion Laboratory (JPL) is costly to operate, maintain, deploy, reproduce, and document. In the present climate of shrinking NASA budgets, this proposal architecture takes on added importance as it should dramatically reduce all of the above costs. Currently, the ground support functions (i. e., receiver, tracking, ranging, telemetry, command, monitor and control) are distributed among several subsystems that are housed in individual rack-mounted chassis. These subsystems can be integrated into one portable laptop system using established MultiChip Module (MCM) packaging technology and object-based software library. The large scale integration of subsystems into a small portable system connected to the World Wide Web (WWW) will greatly reduce operations, maintenance and reproduction costs. Several of the subsystems can be implemented using Commercial Off-the-Shelf (COTS) products further decreasing non-recurring engineering costs. The inherent portability of the system will open up new ways for using the ground system at the "point-of-use" site as opposed to maintaining several large centralized stations. This eliminates the propagation delay of the data to the Principal Investigator (PI), enabling the capture of data in real-time and performing multiple links concurrently from any location in the world. Sample applications are to use the portable ground system in remote areas or mobile vessels for real-time correlation of satellite data with earth-bound instruments; thus, allowing near real-time feedback and control of scientific instruments. This end-to-end portable ground system will undoubtedly create opportunities for better scientific observation and data acquisition.*

### 1.0 INTRODUCTION

Presently, the end-to-end ground functions (i.e., receiver, tracking, ranging, telemetry, command, monitor and control, etc.) of the Jet Propulsion Laboratory's Telecommunications and Mission Operations Directorate (TMOD) are distributed among several subsystems that are housed in individual rack-mounted chassis as shown in Figure 1. Many of the subsystems have high operational (i.e., labor) costs and maintenance overhead mainly due to the support of outdated technologies. Some of the ground functions (i.e., frame synchronization, Reed-Solomon decoding, and formatting) are duplicated by two independent systems: the Deep Space Communication Complex

(DSCC) [1] and the Advanced Multi-Mission operation System (AMMOS) [2]. This leads to unnecessary duplication and hence higher costs.

in one version of the AMMOS system, the telemetry processing, telemetry simulations, and external interfaces are integrated into a laptop. However, all of these functions are implemented in software; and therefore, the maximum data rates are on the order of 300 K bits/sec [2] which is not high enough to support most Earth orbiter missions. AMMOS also lacks the other ground functions (e.g., tracking, ranging, command, network operation control, project operation control, and central processing) to make it an end-to-end ground system. The present AMMOS system also does not have a Viterbi decoder. Due to the computational complexity of the Viterbi decoding algorithm, software cannot be used to implement such a function at the data rate requirements of many missions.

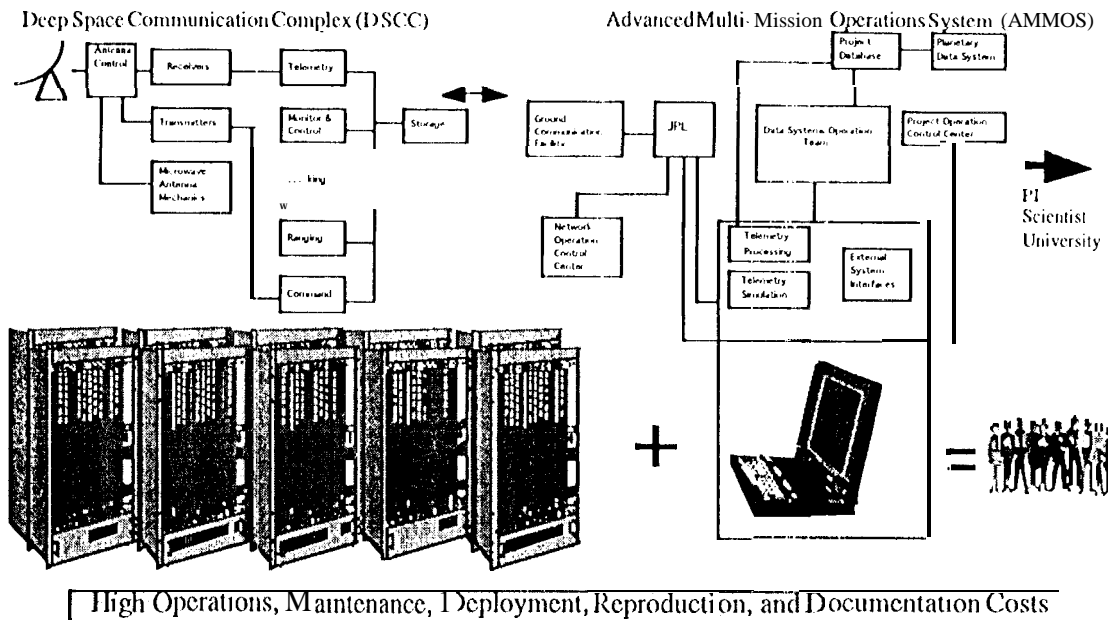


Figure 1 End-To-End TMOID Ground System of Today Uses Too Many People.

in order to reduce cost, JPL is presently automating the operation of the ground system using software to reduce the number of operators through a project known as the Network Control Project (NCP) [1]. However, the maintenance costs of the outdated subsystems have not been emphasized. Also, deployment, reproduction, and documentation costs have not been addressed and remain very high because the end-to-end TMOID ground system of today retains most of the old proprietary subsystems at the DSCC.

The AMMOS concept can be expanded to incorporate more of the ground functions into the laptop by taking advantage of current hardware and software technologies to increase the performance of the laptop. This architectural concept will be discussed in

the next section. After which the key enabling off-the-shelf technologies will be reviewed. Finally, conclusions and future work will be presented.

## 2.0 ARCHITECTURE OF THE PROPOSED END-TO-END GROUND SYSTEM

The proposed architecture of a portable ground system is described in this section. This concept extends the present AMMOS architecture, which performs telemetry simulation and processing. The plan is to integrate other functions of the end-to-end ground system that are presently not available in the AMMOS system into a portable laptop. Hence, the new system will have the following capabilities: tracking, ranging, command, monitor and control, central processing, network operation control, telemetry simulation and processing, and project operation control in one compact system as shown in Figure 2. The bus, the Ground Communication Facility (GCF) portion of the DSCC as shown in the TMO ground system of today (Figure 1) will no longer be necessary. Also, the duplication of the frame synchronization, Reed-Solomon decoding and formatting functions in the DSCC and AMMOS will be eliminated.

In order to achieve the required data rates for Earth Orbiter missions and provide better integrated support for Deep Space missions, the new system will be implemented in hardware. To promote modularity, each of the subsystems' functions (i.e., telemetry, tracking, ranging, and command) will be implemented on separate cards by taking advantage of MultiChip Module (MCM) packaging technology to reduce the size of the integrated circuitry even further. The cards will use the Personal Computer Memory Card International Association (PCMCIA) standard to promote interoperability. The other ground functions will be implemented in object-based software libraries.

For Deep Space and High Earth Orbiter mission support, the future plan of the proposed concept is to keep the antennas, antenna controllers, receivers, transmitters, microwave antenna mechanics, storage or buffers for the data at the DSCC as shown in Figure 2. The bus, the DSCC will still be required for the support of Deep Space and High Earth orbiter missions. This allows the DSCC to concentrate on the unique functions of Deep Space and High Earth Orbiter missions. All of the other ground functions will be integrated into a portable laptop. Due to the portability of the new system, the proposed ground stations can be located anywhere in the world (i.e., DSCC, JPL, University, JPL's office, remote site, or mobile vessel) as shown in Figure 3. The scheduling, prediction, and critical command functions will probably be located at the DSCC though. New low-cost missions (e.g., Millennium and Discovery) can take the portable ground station and hire several graduate students to operate the portable system, thus, reducing cost even further.

For Low Earth Orbiter support, this portable ground system architecture can be further extended to include a built-in receiver with proper shielding to avoid interference between the analog and digital signals (Figure 3). Such a system can retrieve data from a small antenna (i.e., 1 m or less in size). The bus, the complete end-to-end ground system is highly portable. The need to have a permanent site for Low Earth Orbiter ground system support will not be necessary in the future. Nevertheless, data can still be

retrieved using the large 70 m or 34 m antennas located at the station which can then be stored into a local database, and subsequently be accessed via wireless technology for any type of mission support (Figure 3).

There are several advantages to the proposed architecture over and above creating a unified ground system and reducing costs. These benefits include: multiple tasking, closed-loop control, and arraying.

Such a system will allow the PI or scientist to perform multiple tasks concurrently from any location in the world. For example, the PI or scientist can be performing, a Seafloor Geodesy experiment using the Global Positioning System (GPS) while tracking a spacecraft and processing telemetry data of a particular mission at the same time. PI bus, cost is reduced even further since only one operator is necessary to perform multiple functions.

Closed-loop control of the various ground functions has the advantage of enabling the PI or scientist to process the telemetry data in real-time and correlate the data with earth-bound instruments such as GPS and allow near real-time feedback and control of scientific instruments on the spacecraft.

Many small "umbrella-like" antennas can be arrayed together to achieve the performance of a large antenna (e.g., 70 m or 34 m). For instance, Very Long Baseline Interferometry (VLBI) can be performed by the new portable system.

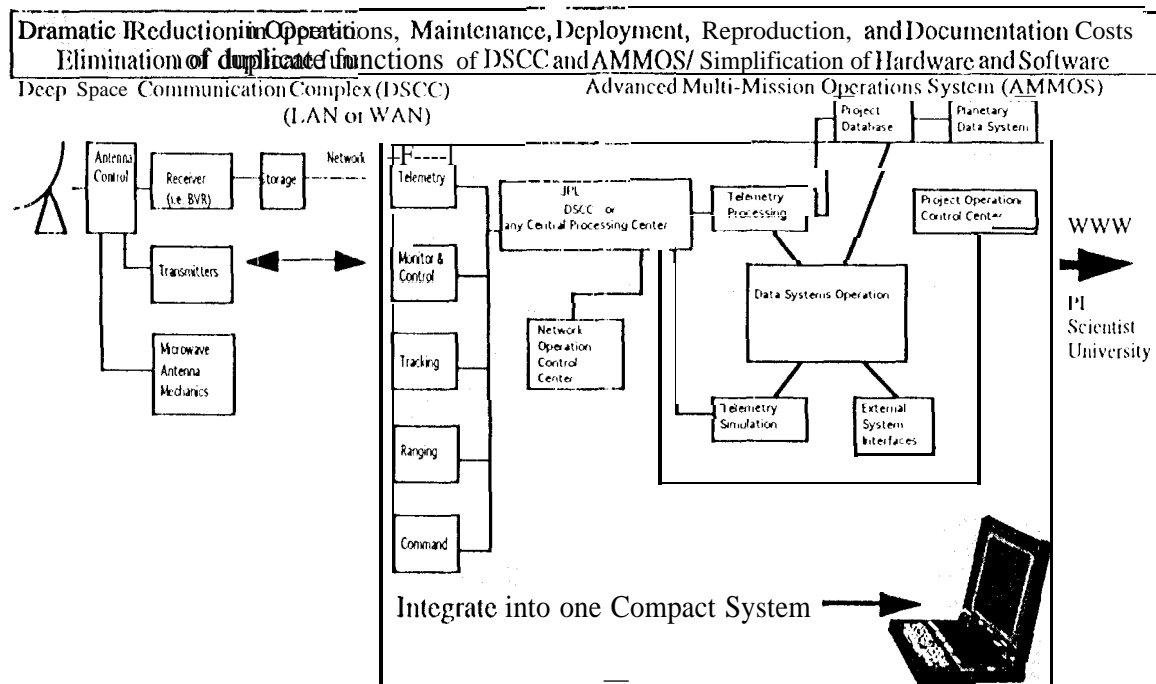


Figure 2 Architecture of the Proposed End-to-End Ground System

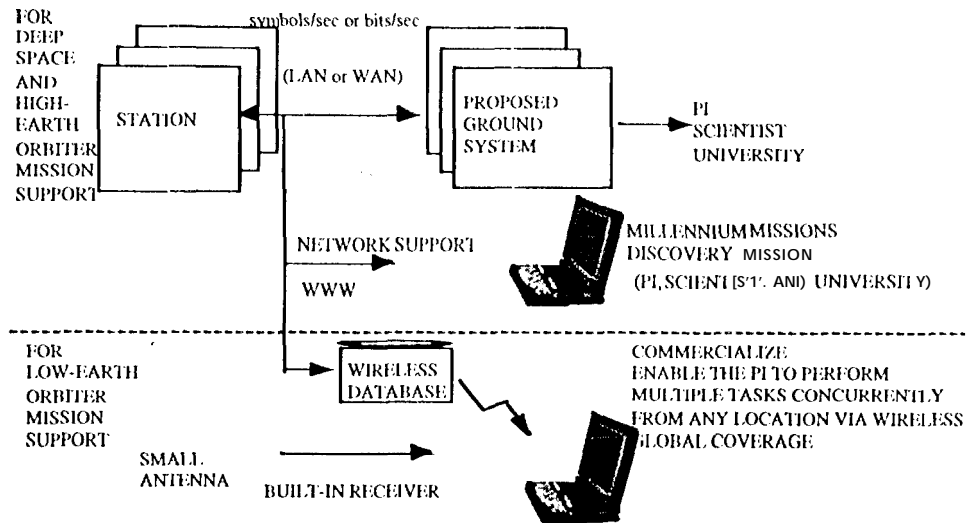


Figure 3 Overall Configuration for the Proposed End-to-End Ground Architecture for Deep Space, High Earth Orbiter and Low Earth Orbiter Mission Support.

### 3.0 KEY STATE-OF-THE-ART TECHNOLOGIES TO ENABLE THE VISION OF THIS LOW-COST MISSION SUPPORT CONCEPT

The technology infrastructure is in place today. With various established COTS technologies, all of the above goals as discussed in the previous section are achievable today.

MCMs has the potential for increased chip density, leading to reduced size of electronic systems. Together with reduced size, MCMs offer a number of advantages. The speed performance is improved due to smaller chip spacings. Reliability is improved due to the reduction of the number of second level connections (i.e., the printed wiring board connections) as noted by Doane and Franzon [3].

MCM provides the structure of repackaging two or more Integrated Circuits (ICs) together into one chip. For example, the integration of off-the-shelf ICs like Qualcomm's Viterbi decoder, Advanced Hardware Architecture's Reed-Solomon decoder, and several Field Programmable Gate Arrays (FPGA) to control the hardware into one MCM package enclosed in a single card can perform the telemetry processing functions [4].

Wireless technology enables the concept of a portable ground system to be located anywhere in the world (e.g., remote areas or mobile vessels). The World Wide Web will simplify the Graphical User Interface (GUI) of the system; and object-based software design will simplify the software design process. All of the above technologies described in this section will be infused into the design of the portable end-to-end ground system.

#### 4.0 CONCLUSION AND FUTURE WORK

A new architecture for ground systems for space mission support is proposed. The proposal expands on the present AMMOS architecture by moving key functions into hardware. Industry standard interfaces will be used to promote interoperability using the PCMCIA bus. Various subsystems can be combined into a small form factor to promote portability and modularity by using MCM packaging. Aside from achieving the primary goal of creating a unified ground system to lower costs, the proposed architecture will open new vistas in the areas of multitasking, closed-loop command and control, and arraying various antennas together.

In the present climate of shrinking NASA budgets, this proposed architecture of integrating most of the ground functions into a portable laptop takes on added importance as it will dramatically reduce all of the above costs by satisfying the following objectives:

1. Re-architect the present end-to-end ground system.
2. Combine some of the common ground functions to simplify the software and hardware.
3. Take advantage of advanced state-of-the-art microelectronics packaging technology using COTSICs.
4. Integrate all the ground functions into one portable laptop system.
5. Replace the proprietary systems with an open system architecture.
6. Open new ways for using the ground system at the "point-of-use" site as opposed to maintaining several large centralized stations.
7. Eliminate the propagation delay of the data to the PI or scientist.
8. Capture of data in real-time by the PI or scientist.
9. Perform multiple tasks concurrently from any location in the world via wireless technology.
10. Create opportunities for better scientific observation and data acquisition.

The present technology infrastructure will allow many PIs or scientists to work together analyzing their data and findings concurrently in near real-time. Thus, the extracted information from the different channels can be correlated together and used more effectively than data from a single channel.

The inherent portability of the system will open up new ways for using the ground system at the "point-of-use" site as opposed to maintaining several large centralized stations. This eliminates the propagation delay of the data to the PI or scientist, enabling the capture of data in real-time and performing multiple tasks concurrently from any location in the world. Sample applications are to use the portable ground system in remote areas or mobile vessels for real-time correlation of satellite data with earth-bound instruments; thus, allowing near real-time feedback and control of scientific

instruments. This end-to-end portable ground system will undoubtedly create opportunities for better scientific observation and data acquisition.

### ACKNOWLEDGMENTS

This work was performed at the Jet Propulsion Laboratory California Institute of Technology under contract with the National Aeronautics and Space Administration. Fruitful technical discussions with B. Anderson, C. Carl, R. J. Cesarone, M.T. Chahine, R.C. Coffin, T. Cole, L.J. Deutsch, C. Edwards, N.R. Haynes, J. R. Kahr, R. P. Mathison, J. C. Peterson, M. J. Rodrigues, R. R. Stephenson, G.P. Textor, P. Varghese, W. J. Weber, and the late Ed Davis are gratefully acknowledged.

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