CONSOLIDATION AND PLANNED DEVELOPMENT OF THE NASA GROUND TRACKING NETWORKS*

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ABSTRACT

The Networks Consolidation Program (NCP) was established by NASA in the fall of 1979 to accomplish the consolidation of the two NASA Ground Tracking Networks into a single unified network. Consolidation of the two networks had been recommended by an all-Networks NASA planning group and presented to NASA top management in October of that year.

The consolidated network of 1986 will make use of facilities that are now included in the Goddard Ground Spaceflight Tracking and Data Network as well as the existing JPL Deep Space Network. These facilities will be combined and modified to provide a consolidated network that is capable of supporting the set of planetary and high earth orbiter missions that are planned for that era.

The drivers for the development of the consolidated network are both technical and economic. The consolidated network must provide the increased sensitivity needed to support the Voyager 2 spacecraft at its distant encounters with Uranus and Neptune in 1986 and 1989. It must provide support to spacecraft in high earth orbit and at the nearby planets at data rates which may be a factor-of-ten higher than present deep space data rates. And it must do both with significantly less cost for maintenance and operation than the sum of the separate networks would have cost in the late 1980's.

This report traces the history of activities and events that led to the decision to consolidate the NASA ground tracking and data networks. It also presents a summary of the planned evolution of the NASA ground tracking networks, from the time of decision in October 1979 through the mid 1980's. It is an updated version of a report presented at the AIAA/NASA symposium on Space Tracking and Data Systems, June 1981.

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INTRODUCTION

During the past few decades, NASA has operated two separate worldwide ground-based tracking and data acquisition networks for support of its various missions. The Spaceflight Tracking and Data Network (STDN) has provided support to all NASA earth orbiting spacecraft: to the rapidly moving low earth orbiters which are visible from any one spot on Earth for only a few minutes at a time as well as to high earth orbiters which have longer orbit periods and are visible for several hours at a time. The primary challenges for the STDN have been to efficiently handle increasing volumes of data, and to operate effectively with the short response times and disconnected tracking intervals which characterize the low earth orbiters. The Deep Space Network (DSN), as its name implies, supports almost exclusively those unmanned exploratory spacecraft which have been sent far from earth. The primary challenge of the DSN has been to provide increasing sensitivity so that it can continue to provide adequate support to ever more distant spacecraft.

Soon, a new resource for tracking and data acquisition support will be added to NASA’s networks. Designated as the Tracking and Data Relay Satellite System (TDRSS) and conceptually a part of the STDN, this resource consists of two geosynchronous satellites together with a single ground terminal in White Sands, New Mexico. These satellites are scheduled to be launched on some of the first operational Shuttle flights, and become operational themselves early in 1984. The TDRSS was conceived as a means of providing improved tracking and data relay service for a large class of the earth orbiting satellites. From their position, the two operational satellites can provide near-continuous real time coverage of most low earth orbiters. The high earth orbiters, however, are outside the field of view of the TDRS for most, or perhaps all, of their orbit, and will continue to require support from ground-based stations.

Figure 1 shows the present locations of the stations of the two NASA networks, together with the coordinates planned for the three TDRS (two operational plus one spare). There are twelve locations in the Ground segment of the STDN, three of which are colocated with the three DSN complexes. Because the TDRSS will provide the communication and tracking support for all of the new low earth orbiters, the workload on the GSTDN is expected to decrease drastically once it becomes operational. Prior to 1979, it had been planned to phase down the GSTDN to only the three core sites which are colocated with the DSN sites, plus the special purpose sites at Merritt Island, Bermuda, and GSFC itself. In 1979, as the anticipated costs of operating the TDRSS became more firm, NASA began to seek ways to further reduce the costs of providing support to those spacecraft which were not TDRS-compatible. This search was performed by a study team composed of representatives from the NASA Office of Space Tracking and Data Systems (OSTDS), the Jet Propulsion Laboratory (JPL), Goddard Space Flight Center (GSFC), and from the

Spanish Instituto Nacional de Tecnica Aerospacial (INTA) and the Australian Department of Science and Environment (DSE, now the Department of Science and Technology). This team recommended that the core sites of the GSTDN be consolidated into the DSN to improve both the effectiveness and the cost aspects of providing support to deep space spacecraft and those high earth orbiters which could not be supported by the TDRSS.

THE 1979 STUDY LEADING TO CONSOLIDATION OF THE NETWORKS

The 1979 study which led to Networks Consolidation was carried out by a team which came to be known as the OSTDS Networks Planning Working Group, and which consisted of representatives from each of the five principally involved organizations: OSTDS, JPL, GSFC, and the Spanish INTA and Australian DSE. The study became fully activated in May of 1979, and concluded by recommending consolidation of the networks to NASA's Associate Administrator for OSTDS in August and to the NASA Administrator in October. After its initial broad definition, the study focused on three primary options, each with several possible variants: (1) the then current plans for the DSN and GSTDN (as a baseline), (2) a hybrid network, which would retain the separate identities of the two present networks, but which would provide enhanced cross-sharing of facilities betwen them, and (3) a single consolidated network, presumably under the management of JPL.

The explicitly stated goal of the 1979 planning effort was to devise a technical and managerial approach that would: (1) provide adequate support for flight projects that cannot be supported by the TDRSS; (2) not preclude other potential NASA missions (e.g., geodynamics); (3) make best use of existing NASA facilities; (4) be consistent with realistic NASA resources; and (5) provide appropriate and useful roles for the several involved organizations, which include NASA Headquarters, GSFC, JPL, INTA, and DSE.

Throughout the planning effort, it was assumed that the TDRSS would provide support for <u>all</u> low earth-orbiting spacecraft by 1984. GSFC would continue to manage the TDRSS including its associated ground station and control center. Also, any proposed consolidation of the GSTDN and DSN was not to take place until the TDRSS was operational and all GSTDN support of low earth-orbiting spacecraft was complete. Phasedown of the unneeded GSTDN facilities would also be completed by GSFC before consolidation.

Two main drivers were considered in developing the study. One was economy. The second was the 1986 Voyager encounter at the planet Uranus, as shown in Fig. 2. Enhancement of the X-band telemetry reception capability, an essential part of the networks consolidation, would be repaid in additional data from this never-before explored planet, if the enhancement could be completed before late 1985.

In the 1979 study, the Consolidated Network, composed of elements from the present DSN and the GSTDN core sites, showed markedly less cost and more capability than the sum of the separate networks. This option was planned around the then-existing plan for the Mark IV DSN, which was to be augmented by GSTDN facilities and resources to support the high earth orbiter (HEO) missions, to enhance the deep space telemetry capability, and to reduce future maintenance and operations costs.

Figure 3 is a top-level overview of the three complexes as they exist today. The networks plan as it was presented proposed that after consolidation, each of the complexes would contain all of the DSN and GSTDN antennas currently at that locale. The 26-meter antennas were, in all cases, to be expanded to 34-meters for increasing X-band telemetry capability through arraying. Enhanced features of the DSN plan for Goldstone were also included. A Signal Processing Center (SPC) would be established at each of the three complexes and provide economies through concentration of functions, with a corresponding reduction in manpower at each complex.

The Networks Planning Working Group concluded its efforts by recommending to top NASA management that the Networks Consolidation Plan be adopted as a baseline plan for the ground tracking networks and that an OSTDS Program Manager be appointed with responsibility for the networks consolidation. The working group further recommended that system engineering and management studies be supported in 1980 to: detail improvements, such as centralized control and signal processing; prepare a detailed Networks Consolidation Implementation Plan that considers life-cycle costs in balance with schedule and front-end costs; integrate network combining with other implementation plans; prepare a Networks Consolidation Management Plan; and prepare a Mission Support Plan for the consolidation period. Design engineering and implementation would begin in 1981 according to detailed plans developed in 1980.

More details of the 1979 study activity may be found in the report “OSTDS Networks Planning for the TDRSS Era” (Ref. 1), which formed the foundation upon which the 1980 and 1981 system engineering and management planning have been based.

DESIGN OF THE CONSOLIDATED NETWORK

The baseline design for the consolidated network has evolved in conformity with the guidelines, constraints, and assumptions specified within the Networks Planning Working Group study. In particular, this baseline design is tailored for the support of deep space spacecraft and those high earth orbiters which are outside of the field of view of the TDRS. Other spacecraft which are not TDRS-compatible are (by policy) not drivers for the design of the consolidated network.

The baseline system design developed for the three complexes (Goldstone, Canberra, and Madrid) includes an antenna corresponding to each of the DSN and GSTDN antennas previously in existence, or planned for, in each of those locations. In particular, the GSTDN 9-meter and 26-meter antennas near each DSN complex in the United States, Australia, and Spain were to be transferred to the Consolidated Network. Because of the variety of ages and designs of the 26-meter antennas, careful engineering analysis revealed that it would be cheaper to replace these with new 34-meter antennas of common design than to expand the old antennas as had initially been proposed.

Typical DSN and GSTDN stations are shown in Fig. 4 prior to consolidation. The DSN 64-, 34- and 26-meter antennas utilize separate signal processing facilities, generally located 5 to 20 km from the NASCOM Communications Terminal. Also, the GSTDN 9-meter and 26-meter antennas communicate directly with GSFC via NASCOM. Figure 4 also shows the general complex configuration after the consolidation of the networks. A Signal Processing Center (SPC) will be established at each of the three complexes. Each SPC provides signal processing and monitor and control facilities for all antennas in the complex, as well as all other functions centralized there. Some detail on these functions can be seen in Fig. 5. The objective of instituting these centers is to provide maintenance and operations cost savings through concentration of functions and a corresponding reduction in manpower.

In the consolidated network being developed, the antennas will be located such that their distance to the SPC is less than 1 km. This facilitates RF signal combining, which enhances arraying of multiple antennas. The resulting increase in effective aperture is necessary for improving deep-space telemetry reception. Antenna arraying capability is to be provided at each of the three complexes. Both the 64-meter and the present 34-meter antennas will continue to be used to track planetary and interplanetary spacecraft. The GSTDN 26-meter and the present DSN 26-meter antennas will be replaced by new 34-meter high-efficiency S- and X-band listen-only antennas. These antennas will be capable of supporting either deep space or high earth orbiter missions. When appropriate, tracking of planetary spacecraft will be augmented by arraying one or more of these high efficiency antennas. When all high-efficiency antennas at a complex are arrayed together with the 64-meter, as they will be for the Voyager encounter with Uranus, telemetry performance is equivalent to that of a single 85m antenna. The 9-meter antennas will not be used to support planetary and interplanetary missions.

Two types of drivers influence the design of the consolidated network. One of these is economy of maintenance and operation, which affects mainly features which are internal to the network. This includes simplifying the equipment configuration, simplifying the operational control of that equipment, and eliminating old and hard-to-maintain equipment as much as practicable. An essential part of this move toward economy is the elimination of mission-peculiar processes and the development and use of standard data handling formats and procedures for all missions. Better service can be provided to all network users if the commonality of their needs is emphasized and any specialized needs are satisfied in their own mission control center.

The second type of driver for consolidated network design is for capabilities needed to support specific users of the network. The spacecraft which, taken together, specify these capabilities are listed in Table I. Many of these can be supported by the present DSN. Some of them represent drivers for new capability which will then become useable by, and useful to, missions which will follow them.

The OPEN spacecraft family (Origin of Plasmas in the Earth's Neighborhood) makes measurements of particles and plasmas in the earth's magnetosphere and the solar wind, to help model energy flows from the sun, and, toward, around, and thence away from the earth. The OPEN Mission will operate four separate spacecraft, as shown in Fig. 6. Taken together, their data acquisition rate is high compared to typical deep space probes, and thus they become a driver for the data collection rate in the consolidated network. An increased data collection rate will also be needed by the Venus Orbiting Imaging Radar (VOIR) Mission.

The Voyager Mission, Fig. 2, is the leading example of a deep space mission for which increased telecom link performance is a primary driver. The Voyager mission was launched in 1977 as a dual spacecraft mission to Jupiter and Saturn, with a latent option to extend the flight to Uranus and Neptune. Today, Voyager I has completed its primary mission, and is headed out of the Solar System. Voyager II is rapidly approaching Saturn, and will be directed from there to fly past Uranus in January of 1986 and Neptune in August of 1989. The distance from Earth to Jupiter was approximately 6 Astronomical Units (AU) at the time of encounter. The distance to Uranus will be approximately 20 AU, and the distance to Neptune 30 AU. Because of the increased distance, the signal received from Voyager will be more than 10 dB weaker at Uranus than Jupiter, and almost 14 dB weaker at Neptune than Jupiter.

With the Voyager already in flight, improvements in the telecom link performance can only be achieved through improvements in the ground system, such as will be obtained through arraying all the large antennas at each complex of the consolidated network. The Voyager encounter with Uranus is thus the primary schedule driver for the high-efficiency 34m antennas, and hence also for the schedule for the consolidation of the NASA networks. The Voyager encounter with Neptune will be a driver for further increases in the telecom receiving capability by 1989. As perceived now, this need will be met through providing additional high efficiency antennas which would be arrayed to support the Voyager at its Neptune encounter. The first two of these additional antennas are destined for Goldstone on a schedule which will make them available for support of the Voyager Uranus encounter in 1986.

Since 1958, The Deep Space Network has provided the most sensitive receiving capability and most powerful and effective command and tracking facilities in the world. That is true today, and will be true of the consolidated network in 1986 and beyond. Table 2 summarizes some of the pertinent characteristics anticipated for the planned network elements of 1986.

Discipline for the system design process through 1980 has been provided by four Formal Reviews, beginning in May of 1980, and ending in January of 1981. The baseline network design as needed to support the current and planned missions of Table I was defined as of October, 1980, and work begun to plan the implementation process. The top-level implementation plan for consolidating in accordance with this design was reviewed and approved by NASA in January, 1981. Engineering studies for refinement of this plan have continued since that review.

The configuration of the consolidated network after 1986 will depend in a detailed way upon the outcomes of these engineering studies, as well as upon details of the mission set to be supported by the network. Deep space spacecraft will continue to need increases in the telecom link performance. This has in the past induced increases in the downlink communications frequency from L- to S- to X-band as well as increases in the ground receiving apertures. Future frequency increases to K-band are being contemplated, as well as the above-noted increases to the aperture. Changes such as these are always associated with a specific mission need: e.g., the need for telecom capability for the Voyager Uranus and Neptune encounters; the need for increased radiometric precision which would be made possible by an X-band uplink for Solar Polar or Starprobe; and the need for increased telecom link capability which would be made possible by a K-band downlink for a future Far Outer Planet Mission. More information on the technological and Mission drivers for future network development may be found in Ref. 2: “NASA Tracking and Data Acquisition in the 1990s - Part I.”

SUMMARY AND PLANS: 1981-85

The planned deployment of the TDRSS early in this decade set the stage for significant further changes in the NASA Tracking Networks. The host of low earth orbiting satellites currently supported by the GSTDN will be replaced by similar spacecraft which are compatible with and are supported by the TDRSS. This change will present a drastic reduction in the workload of the GSTDN, making it uneconomical to continue the operation of that network as a separate unit to support the much smaller set of high earth orbiters. The deep space users, meanwhile, have a need for increased ground receiving sensitivity which can most directly be obtained through arraying of the large antennas. Phase down of parts of the CSTDN and consolidation of the remnants into the DSN is therefore a natural consequence of NASA's desire to provide increasingly effective and affordable spacecraft support.

The actual transition from separate GSTDN and DSN to a single NASA consolidated ground network will occur in the brief two-year span of time between the operational date of the TDRSS and the encounter of Voyager with Uranus. There is a great deal of planning, engineering, and implementation needed to make that transition, and yet little slack in the schedules for that work, which has been underway since early 1980. We believe that the consolidation of the networks can be accomplished on the schedules set forth, and completed prior to the Uranus encounter of Voyager. Once consolidation of the networks has been accomplished, NASA will have a less costly yet improved capability to provide effective support to deep space spacecraft and those high earth orbiters which cannot be supported by the TDRSS.

REFERENCE

1. Layland, J. W., OSTDS Networks Planning for the TDRSS Era, Report prepared for NASA Office of Space Tracking and Data Systems, Washington, D.C., January 1980.

2. Smith, J. G., and J. A. Hunter, "NASA Tracking and Data Acquisition in the 1990s: (I) High Earth Orbit and Planetary Spacecraft Support," to be published: AIAA/NASA symposium on Space Tracking and Data Systems, June 16-18, 1981.

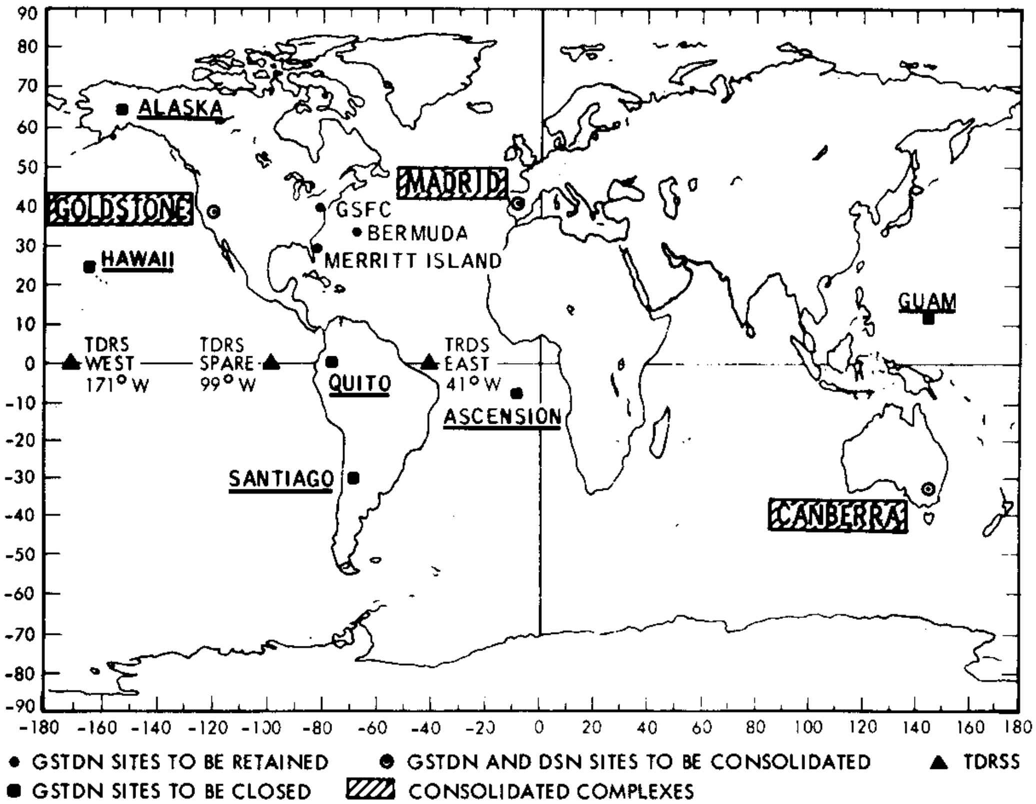

FIGURE 1. LOCATION OF NASA GROUND STATIONS

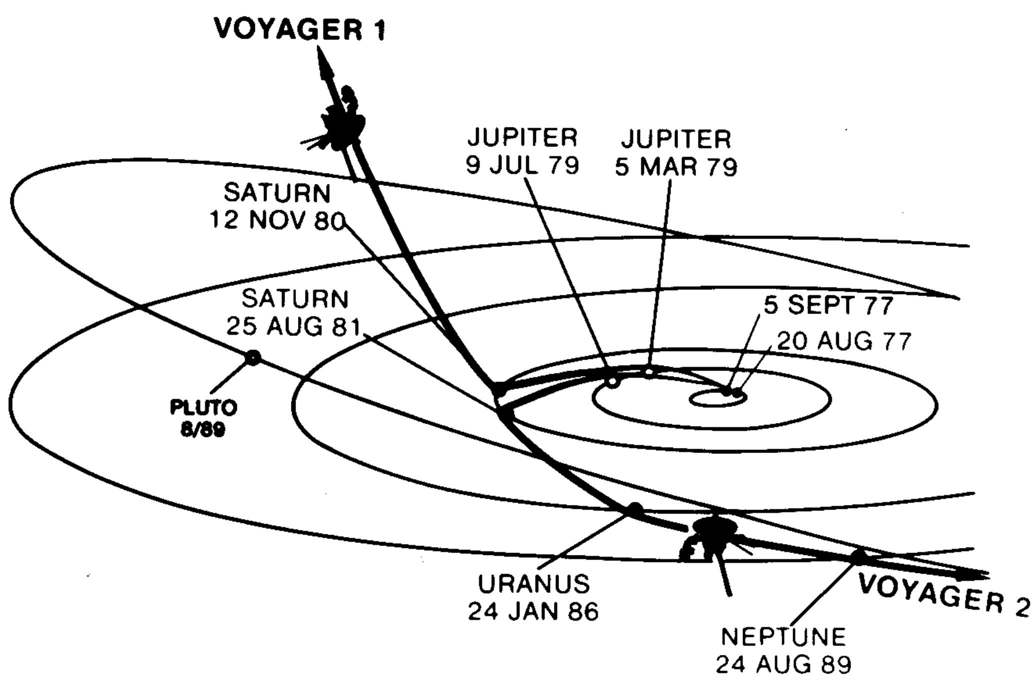

FIGURE 2. VOYAGER MISSION

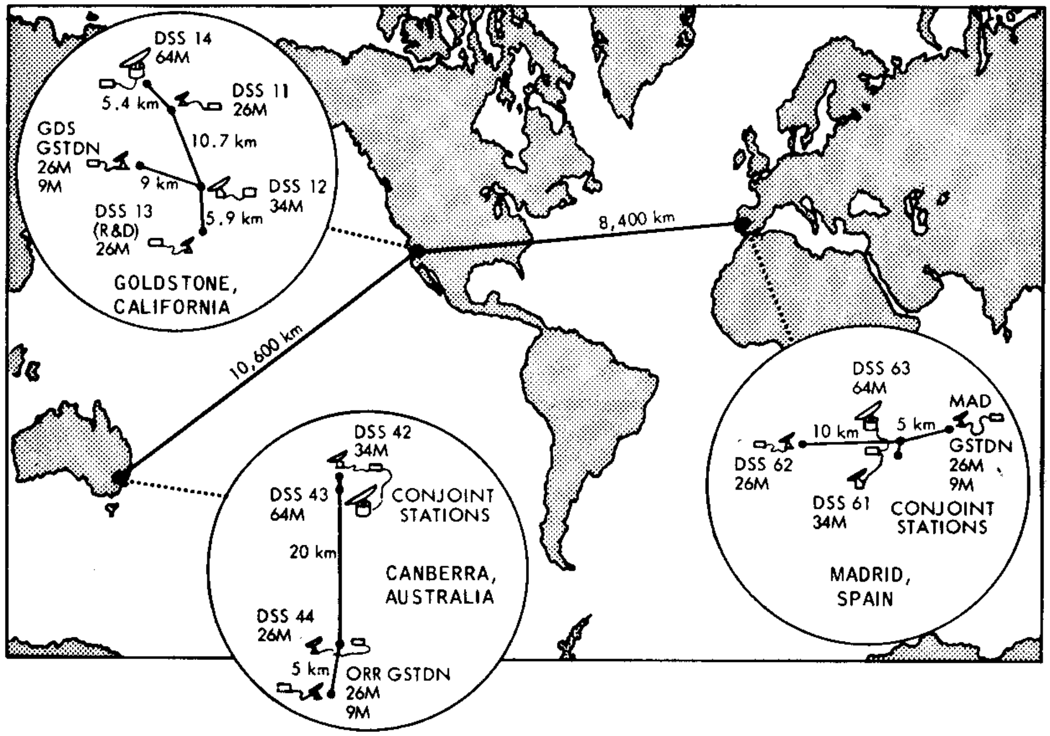

FIGURE 3. NASA DEEP SPACE NETWORK COMPLEXES WITH COLOCATED GSTDN STATIONS

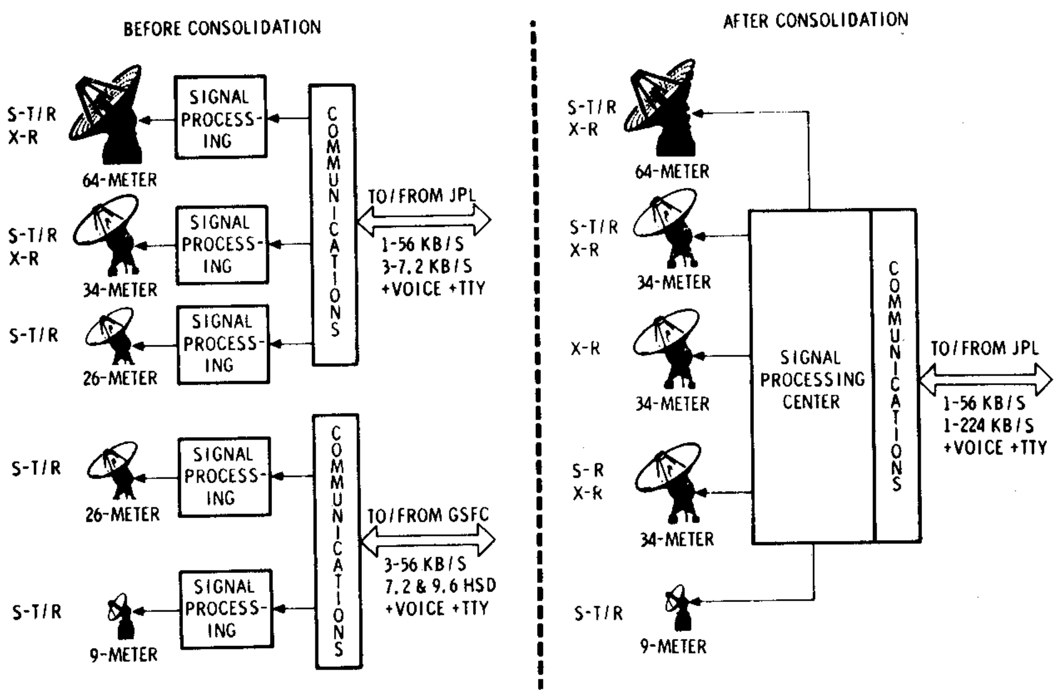

FIGURE 4. TYPICAL COMPLEX BEFORE AND AFTER CONSOLIDATION

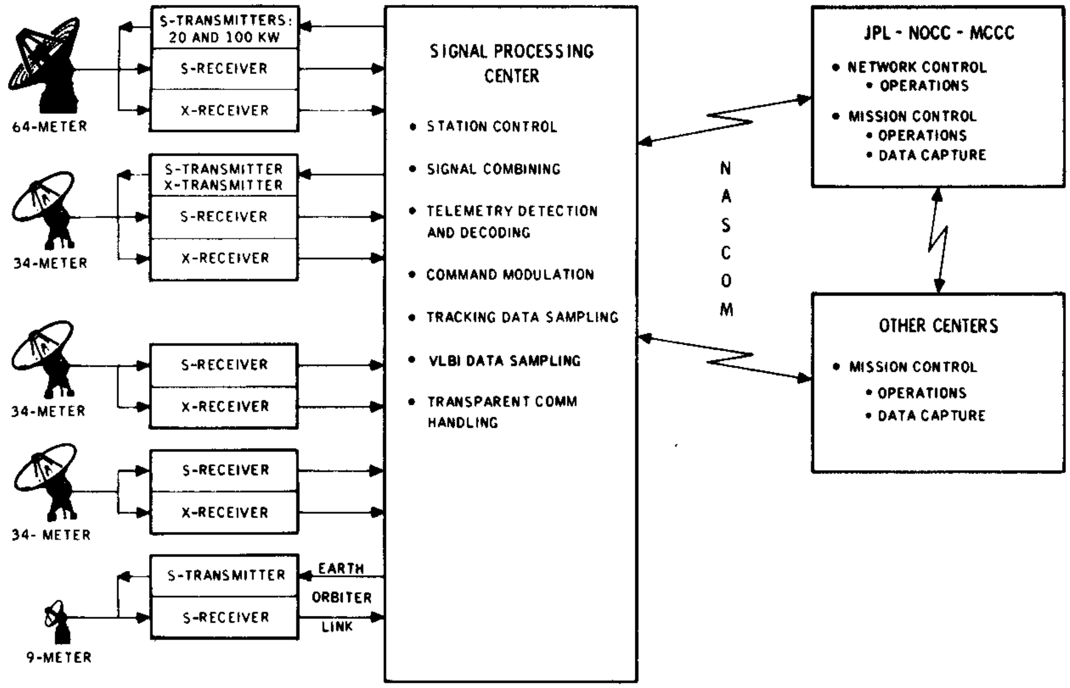

FIGURE 5. NETWORK CONFIGURATION - OVERSEAS COMPLEX

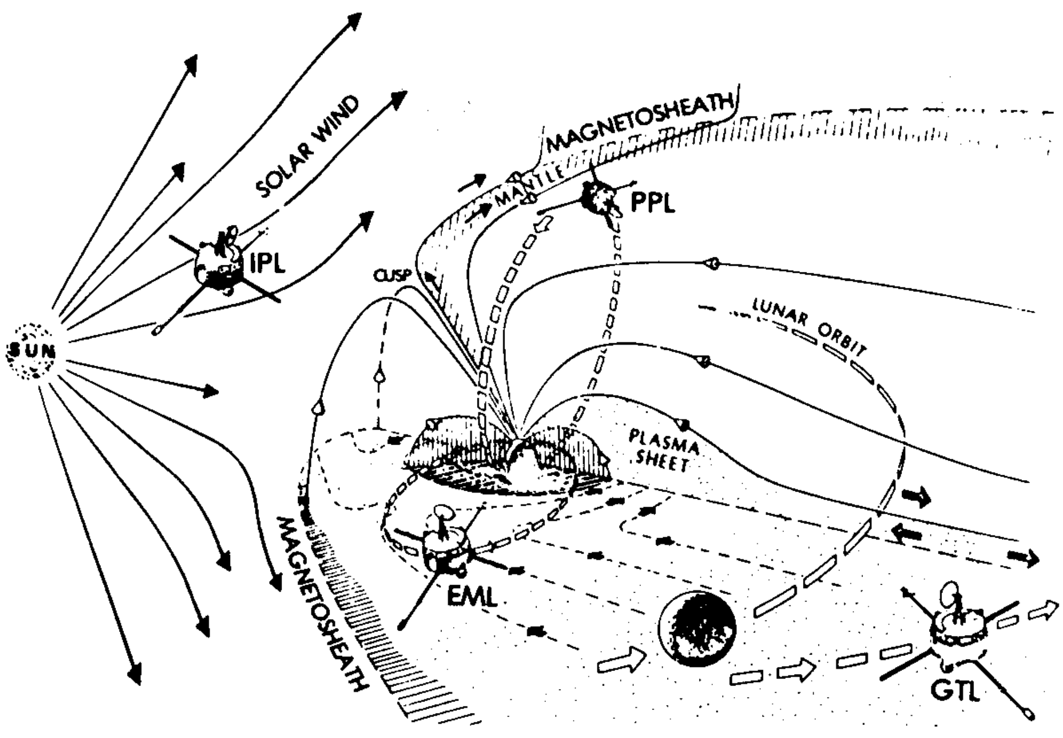

FIGURE 6. OPEN MISSION

TABLE I. REPRESENTATIVE MISSIONS SUPPORTED AFTER NETWORKS CONSOLIDATION

- HIGHLY ELLIPTICAL EARTH ORBITAL MISSIONS NOT TDRSS COMPATIBLE
  - CURRENT
    - ISEE 3
  - FUTURE
    - OPEN
  - PLANNED
    - AMPTE

- DEEP SPACE MISSIONS
  - CURRENT
    - PIONEER 6-9, 10, 11
    - VOYAGER 1, 2
    - VIKING LANDER
    - PIONEER VENUS
  - PLANNED
    - GALILEO ORBITER, PROBE CARRIER
    - SOLAR POLAR
  - FUTURE EXAMPLES INCLUDE
    - VOIR
    - SATURN ORBITER DUAL PROBE
    - JUPITER - NEPTUNE FLYBY
    - JUPITER - PLUTO FLYBY

TABLE 2
PRELIMINARY 1986 CONSOLIDATED NETWORK CHARACTERISTICS

FUNCTION	64-METER DEEP SPACE		34-METER TRANSMIT/RECEIVE HEO MODE	34-METER TRANSMIT/RECEIVE DEEP SPACE MODE		34-METER L.O. TWO PER COMPLEX		9-METER TRAN/REC HEO
Uplink Frequency	2110-2120		2025-2120	2110-2120		N/A		2025-2120
Uplink Power - KW	20 or	100	20	20		N/A		10
EIRP - DBM	133.6	140.7	128.3	128.3				113.2
Downlink	S-Band	X-Band	S-Band	S-Band	X-Band	S-Band(one)	X-Band	S-Band
Frequency, Mhz	2270-2300	8400-8440	2200-2300	2270-2300	8400-8440	2200-2300	8400-8500	2200-2300
Antenna Gain, dbi	61.6	72.1	55.8	56.0	66.5	56.0	67.3	44.1
Sys. Temp., K	18-26	21	60	21.5-35.5	25	60	18.5	175.4
G/T, db	47.5-49.1	58.9	38	40.5-42.8	52.5	38.2	54.6	21.7
Antenna Tracking Rate	.25°/Sec		.4°/Sec			.4°/Sec		4.0°/Sec