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An Overview of the Mark IVA Monitor and Control System

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The Deep Space Network Monitor and Control System was completely changed during the conversion from the Mark III to the Mark IVA configuration. The new configuration employs shared data processing equipment between several co-located antennas, and incorporates much greater centralization of operations functions. The new configuration is described and its performance is compared to that of the Mark III era.

I. Introduction

In 1985, the Deep Space Network (DSN) was upgraded from the Mark III configuration to the Mark IVA configuration. The objectives of this upgrade were: (1) to replace aging equipment in the DSN, and (2) to change from stand-alone stations (each with one antenna) to a Signal Processing Center (SPC) fed by several co-located antennas.

To effect the upgrade, the entire Monitor and Control System (MON) was replaced. This was done in order to establish centralized control of all equipment in each of five facilities. These are: (1) The three Deep Space Communications Complexes (DSCCs) with their Signal Processing Centers, (2) the ground communications Central Communications Terminal (CCT), and (3) the Network Operations Control Center (NOCC).

Centralized control is considered to be essential to enable complicated operations activities and to control operational costs. The SPC configuration was selected because it requires less equipment at each DSCC. For example, if there are three stand-alone stations, *six* telemetry processors are required (one on-line and one for backup at each station), in order to meet the functional availability requirement. In the centralized SPC configuration, however, only *four* telemetry processors are required (one on-line for each station, and one which is a backup for all three stations).

The Mark IVA MON (see Fig. 1), with a few exceptions, provides the capabilities for operating subsystems at each facility from a central point. It acquires data to allow an operator to monitor the status and performance of the subsystem and allows centralized control of subsystem operation. The control function provides the capability for initialization, configuration, calibration, mode selection, and shutdown of DSN equipment. Some systems (such as Telemetry), however, are composed of subsystems which reside in more than one facility and, therefore, are not centrally controlled.

In addition to centralized facility control, the MON also provides operator consoles for coordination and monitoring of the Deep Space Network. Network monitoring includes generation of Network Performance Records (NPR) and displays for evaluating performance of the stations and delivery of received data. For network control, the MON distributes predictions, sequences of events (SOEs), schedules, and standards and limits (S&L) to the stations for use in facility operations. At the facility level, the MON distributes control directives and provides displays of responses, status, performance parameters, configuration data, logs, and failure and diagnostic data to operations and maintenance personnel.

Centralization of the monitor and control of subsystems at the DSCCs was accomplished by the utilization of minicomputers or microprocessor-based controllers within subsystems for interfacing with the DSCC Monitor and Control Subsystem (DMC).

The Mark IVA configuration of the MON includes new operator terminals along with new subsystem interfaces and displays. Real-time operator input/output (I/O) devices at the subsystems are specifically excluded for all new equipment implemented into the network.

At the DSCCs, a new Antenna Pointing Subsystem (APS) with an electrical interface has replaced the former APS with its papertape-driven operation and associated problems. Also, a minicomputer-based Test Support Assembly (TSA) has been added to generate telemetry simulation streams under central operator control. The TSA replaces the Simulation Conversion Assembly (SCA) formerly used.

II. Functional Allocations Within the Monitor and Control System at the Facility Level

Facility level MON functions are allocated to the DSCC, CCT, and NOCC.

Each subsystem controller within a facility interfaces with and responds to control of the associated facility controller. The subsystem provides the capability for self-monitoring and supplying the facility controller with status, performance, configuration, failure and diagnostic data. In turn, the facility controllers send facility configuration, status, and data flow information to the NOCC for presentation to the Network Operations Control Team.

III. Functional Allocations of the Monitor and Control System Within the Facilities

A. Deep Space Communication Complex

The monitor and control functions at the DSCC can be divided into three areas, (1) the DSCC Monitor and Control (DMC), (2) the DSCC subsystem processors and controllers, and (3) the Local Area Network (LAN). The functions of the DMC and the DSCC subsystem processors and controllers support the concept of the station's centralized monitor and control. The keyboards and display devices necessary to perform pre-pass readiness tests, scheduled tracking activities, post-pass procedures, and various tests to verify proper operation are located at a central control and display position at the DSCC. The configuration also permits centralized control of simultaneous tracking and data playback activities.

1. The DSCC Monitor and Control Subsystem (DMC). One of the functions of the DMC is to store the support data (predictions, schedule, SOE, and S&L) received from the NOCC so that operations can be conducted using these data. After assembling the DSCC equipment into links (strings of equipment required to support a spacecraft pass), the operator at each link console can initialize the assembled equipment and operate the link. The DMC operators (via input/output devices) monitor the performance and data accumulation and the operations of each subsystem at the DSCC.

Each DSCC generates an operations log containing inputs, responses, alarms and events in addition to generating and recording an Original Data Record (ODR) containing data products generated at the station.

DMC operations are divided into two separate areas as follows:

(a) *Complex Monitor and Control.* The Complex Monitor and Control (CMC) processor provides the operator interface for the assembling of DSCC resources into links for mission support. In addition, the CMC, (1) generates configuration and status data for facility and network monitoring, (2) receives support data from the NOCC, and (3) stores and distributes these data to the other subsystem controllers. Also, the CMC receives, processes, and displays event/alarm messages and maintains an operations log. The configuration of the DMC is such that the CMC is not in line with the data flow from the links. Hence the links (once established) are not affected by a CMC failure.

(b) *Link Monitor and Control.* The Link Monitor and Control (LMC) processors provide the operator interface for monitor and control of the equipment assigned as a link to support a particular tracking pass or operation. Like the CMC, the configuration of the LMC is such that if the LMC experiences a failure or shutdown, there is no impact to data flow in other systems.

The LMC accepts and processes status, performance, and configuration data from the other subsystem controllers and generates monitor data blocks for flight projects. The LMC also receives and displays event/alarm messages and display data from other subsystems. In addition, the LMC generates and maintains an operations log for operator, maintenance, and analyst use. This log includes operation directives, subsystem responses, and event/alarm messages received from other subsystems.

2. **DSCC Subsystem Processors and Controllers.** The DSCC processors accept operator control inputs from the DMC, control and monitor their lower level assemblies, and generate responses, alarms, events, display and monitor data for use by the real-time operator. A self-test capability is incorporated into these processors.

3. **Local Area Network.** The Local Area Network (LAN) is the network through which the subsystems at the DSCC communicate. The DMC controls the routing map and monitors the activity of the LAN. The types of data monitored include the availability of, and the statistics for, each interface port.

B. Central Communications Terminal (CCT)

The Central Communications Terminal (CCT) Monitor and Control Subsystem (CCM) provides the man-machine interface for CCT facility operation through control of routing, processing, display of status and performance data, and generation of an operations log. The CCT also transmits monitor data to the NOCC for use by the Network Operations Control Team (NOCT).

In the same manner as at the DSCCs, the CCM sends control data to lower level assemblies and receives responses, status, and performance data from them for processing, display, and generation of data to be forwarded to the NOCT.

C. Network Operations Control Center

The NOCC Monitor and Control Subsystem (NMC) and the NOCC Support Subsystem (NSS) combine to provide control of the DSCCs. The NSS generates and distributes support data including predictions, DSN operations sequences, and schedule data for the DSCCs. The NMC provides the man-machine interface for control of other Real-Time Monitors (RTM) which monitor and report their system's configuration and performance to the NOCT. In addition, the NMC receives data from facility controllers and provides NOCT personnel with details of the performance, status, and configuration of the DSN. All systems data flow are monitored by NOCT personnel to ensure that mission support requirements are met.

The basic functions of the NOCC MON are further defined in the following areas:

1. **The NOCC Monitor and Control Subsystem (NMC).** The NMC provides the operator interface for monitoring and controlling of the equipment at the NOCC (facility control) and for monitoring the operation of the DSCC and the CCT (network control).

(a) *Operator Interface*. The operator interface provides the capability for the Network Operations Control Team (NOCT) to monitor and analyze the status, performance, and operation of the DSN without being in the data stream between the spacecraft and the project users. The NOCT operates in a Network Control Area which houses multiple consoles for use by the various NOCT personnel (Operations Chief, Track Controllers, etc.). Currently there are four consoles for Track Controllers. Each supports up to six projects simultaneously, with display selections at each console made independently of one another.

The NOCT coordinates the support of all scheduled activities and verifies that the DSN support meets the established and scheduled commitment. This coordination includes providing real-time interfaces with the flight projects and the DSCCs. The NOCT also assists with fault isolation and recovery, including reallocation of network resources.

(b) *NOCC Operation*. The Network Monitor Processor (NMP) is part of the NMC subsystem and is the interface hub for NOCC operations in that it receives and processes data from the DMC, CCT, other NOCC RTM subsystems. It also provides information, along with other RTMs, to the NOCT for real-time analysis of the status, performance and operation of the DSN. The processing functions of the NMP are performed in conjunction with other assemblies of the NMC which provide alphanumeric displays, graphic plots, printers, and the operator I/O devices.

The other NOCC RTMs (Command, Radio Science/VLBI, Telemetry, Tracking) monitor data received from subsystems at the DSCC and, in some cases, compare them to predictions provided by the NOCC Support Computer (NSC). The RTMs generate status, residuals, and display frames showing the configuration and performance of their associated system. These data are transmitted to the NMC for NOCT use. In addition, a System Performance Record (SPR), (an archival file of operations) is also generated by the RTMs.

(c) *Network Control*. The NMP provides for network control by the presentation of displays from the RTMs and by presentation of selected detail information from subsystems at the DSCCs.

IV. Hardware Configuration

A. Computers

1. **Deep Space Communications Complex.** The Modcomp II computers in use during the Mark III configuration have been retained for use by the ARA, CMD, DTM, and DTK

subsystems (see Fig. 1) during the Mark IVA era. New Modcomp Classic 7845 computers have been implemented for use by the APS, DMC, DSP, and DTS subsystems. The DMC contains two computers (one prime and one backup) for the CMC and three computers for the LMC. Each of these computers uses an IEEE-488 interface for connection to its LAN-Network Interface Unit (NIU).

The DMC interfaces with the RCV, PPM, TXR, and FTS subsystems using (8080/8086) microprocessor-based controllers that have been added to these subsystems. These controllers are fitted with RS-232 interfaces for connection to their LAN-NIU.

The APS computer also interfaces with lower tier microprocessor-based controllers which drive the antennas.

2. **Central Communications Terminal.** Existing Modcomp II computers have been retained for the Error Correction and Switching Assembly (ECS), the CCM, and the Network Communications Equipment (NCE). These computers control the routing of data among the Project Operations Control Centers (POCC), the NOCC, and the Mission Control and Computing Center (MCCC).

3. **Network Operations Control Center.** The Modcomp II computers used in the NOCC have been retained. Two VAX 11-780 computers have replaced the Sigma V computers previously used for the generation of support data. Four Star Switch Controllers (SSCs) provide the interconnection among the RTMs in the NOCC.

B. Mass Storage

1. **Deep Space Communications Complex.** With the exception of tape recorders used for generation of Original Data Records by telemetry, radio science/VLBI, and ARA processors, there is no provision for mass storage of data at the DSCC. The Modcomp II computers do have 2.5-Mb disk drives that are used for program loading and temporary storage of data. The Modcomp Classic computers have a 6.5-Mb cartridge/Winchester drive for program loading and temporary data storage. Program and temporary data storage (logs, predictions, etc.) in the CMC and APA is provided by 256-Mb disk drives attached to these units.

2. **Central Communications Terminal.** The hardware configuration in the CCT remains as it was in the Mark III configuration, with tape drives for the temporary storage of data records, and disk drives for program loading.

3. **Network Operations Control Center.** In the NOCC, 2.5-Mb cartridge disk drives have been retained for the Modcomp II computers. Each VAX 11-780 uses a 256-Mb disk drive for data storage.

C. Man-Machine Interface

1. **Deep Space Communications Complex.** While not centralized to the extent provided by the Mark IVA configuration, the Mark III DSN included a Data Systems Terminal (DST) for monitor and control of data system processors and a console for monitor and control of receiver equipment. At the DSCC, the DST and the Station Monitor and Control (SMAC) console were replaced by two consoles (prime and backup) and three LMC consoles (one per link). The CMC console has two keyboards (prime and backup), five 19-inch color graphic displays (three of which are normally active), and a voice subsystem interface.

The LMC console has one keyboard, three 19-inch color graphic displays, and a voice subsystem interface. Closed circuit TV monitors are mounted on top of these consoles for antenna surveillance.

At both the CMC and the LMC, the lower half of the console center screen is reserved for operator input, subsystem responses, event/progress advisory messages, and macro-procedure execution listings. The upper half is reserved for alarm messages. The remainder of the screen display areas are available for operator selected 1/4- or 1/2-screen displays that are generated by the DMC or other subsystems.

Local terminals are used for program loading at those computers that have disks (with the exception of the DMC). One of the remaining implementation items is the elimination of local consoles and terminals by establishing remote initialization of all computers and controllers.

Tape mounting and handling is still necessary for ODR recording. It is performed at recorders which are located in the computer area, not in the control room. Sometimes, the link operators load and label their own tapes, and sometimes a roving operator performs the task. The roving operator is assigned to those assemblies which require control and which have not been adapted for central control. Centralization of those controls is planned.

2. **Central Communications Terminal (CCT).** The CCT man-machine interface will remain as it was in the Mark III configuration. There are two consoles; one is operated by the Communications Chief (Comm Chief), and the other is operated by the Communications Technician (Comm Tech). Each of these consoles has keyboards, cathode-ray tubes (CRTs), telephones, and a voice subsystem interface. Both the Comm Chief and the Comm Tech have access to CCT status and configuration displays as well as NOCC-generated system displays.

3. **Network Operations Control Center.**

(a) *Network Operations Control Area.* Network Operations Control Area (NOCA) man-machine interface is similar to what it was in the Mark III configuration. There is a console for the Operations (OPS) Chief, four track-controller consoles, two analyst consoles, and a support console. Each of these consoles has CRTs, a display selector, a telephone, and a voice subsystem interface. There is a separate keyboard-CRT terminal that provides direct access to the RTMs in the Network Data Processing Area (NDPA).

Displays are generated by the RTMs and contain detailed performance and configuration data (e.g., TPA no., channel no., frame size, bit rate, and bit error rate). Graphic displays, such as the point plot of antenna pointing residuals, are also provided. It is a function of the operators to combine this information with schedules and operations sequences to ensure that the support provided is in accordance with the established commitment.

(b) *Network Data Processing Area.* The man-machine interface in the Network Data Processing Area (NDPA) is very similar to what it was in the Mark III configuration, although there has been some change in the hardware. Simple CRT terminals have replaced most of the Megadata Input/Output operator terminals, and dot matrix printers have replaced G.E. Terminets. The NDPA operators handle the loading and initialization of the RTMs. They also operate tape drives for generating data records.

D. Local Area Network

1. **Deep Space Communications Complex.** The LAN hardware configuration of the DSCC has been completely replaced by new technology. The previous 16-port SSCs have been replaced by an Ethernet CSMA-CD bus. (CSMA-CD is an abbreviation for Carrier Sense, Multiple Access, with Collision Detection.)

The LAN is composed of a coaxial cable bus which connects a network of transceivers, Network Interface Units (NIUs) and computers. The NIUs are microprocessor-based, and handle communication protocols with host computers and other NIUs. All of the Modcomp II, Classic computers, and microprocessor-based controllers are connected to the LAN. The computers and controllers exchange datagrams containing monitor, control, and system data. The system data include command, telemetry, tracking, radio science, VLBI, and telemetry simulation.

Because DSCC-10 is physically too large for a single Ethernet, the LAN at DSCC-10 has a bridge to another network at a remote station (DSS-12) which is 20 km away.

Each LAN is supported by a redundant Network Configuration Facility (NCF) that provides program storage (on disk) and is a server for downline loading of NIU software. Datagram routing is accomplished by the use of functional addressing, which allows substitution of equipment without the need for a change of destination coded by originators. The functional-to-physical address translation is accomplished in the NIU. The address translation table is loaded into all NIUs with one broadcast message.

In addition to the datagram service, the network provides virtual circuit capability. Virtual circuits are used to support printers at remote sites. Eventually, all printers and consoles will be connected using virtual circuits.

2. **Central Communications Terminal.** The Mark III, 16-port SSCs have been retained in the CCT. Three of these SSCs are connected to provide redundant operation.

3. **Network Operations Control Center.** The Mark III, 16-port SSCs have been retained in the NOCC. Four of these SSCs are connected to provide redundant operation.

V. Performance

A. Response Time

Because human operators are used at the DSCC, the response time of the computers and controllers reporting to the DMC computers is very important. The nominal response time has been established as one second. Many of the control directives are serviced within this period. There are some directives (such as moving the antenna to point), however, which cannot be serviced within this time. For those cases where processing operations require more than one second, the computer or controller immediately responds with a "processing" message and sends a completed "advisory" later.

B. Computers

The Modcomp II computers are using essentially the same software as was used during the Mark III configuration. They still perform fairly well, but it should be noted that some problems associated with real-time operations do occur. Some of these problems are occasional computer halts causing reloads and restarts. The computer memory (128-K bytes maximum) is very limited, and this makes program changes difficult.

The microprocessor-based controllers are generally successful. The 9600-baud interfaces are fast enough, there is plenty of memory available, and the reliability is high.

C. Staffing

One of the objectives of the Mark IVA implementation was to reduce the staffing level of the operations crews at the DSN facilities. This objective has been met with the centralization of the monitor and control functions at all the facilities. The central monitor and control concept, which provides fast and easy access in setting up and configuring links and associated systems, has been widely accepted by the real-time operators even though the work load on DSN operations has greatly increased. It should be noted that the decrease in operations staff required an increase in the systems knowledge of the individual operators since they became responsible for the operation of an entire link instead of only a portion of one.

D. Functional Availability

The functional availability requirements are unchanged: 99% for single antenna telemetry (96% in cruise mode) and 99.5% when more than one antenna is available for use.

At the time of the Mark IVA implementation, there was a step decrease from 99% to 96% in the telemetry system functional availability. There were many factors contributing to this decline, but a major problem appears to be a lack of familiarity with a totally new MON and LAN. Because the operations training program did not have an interactive simulator available, most of the training was accomplished on live spacecraft. The result of this was high operator stress and less than required performance.

Also, most of the subsystems did not exhibit adequate functional availability when they were first implemented, but subsequent testing and debugging of the software (in 1985) brought most of the subsystems back to the level of functional availability of the Mark III configuration. The control of antenna pointing was one of the most severe problems, but now appears to be adequately corrected.

The one-hour specification limit for routine pre-track calibrations remains unchanged for Mark IVA. After an initial learning period, where problems often led to excessive calibration times, the Mark IVA meets this requirement.

VI. Conclusion

While it is true that performance suffered from implementation problems and a relatively lengthy learning period of approximately one year, the DSN recovered from the transition to the SPC configuration and central control and greatly exceeded performance requirements in the support of the Voyager-Uranus encounter. The Mark IVA objectives were achieved without seriously degrading the high performance standards of the DSN, and thereby demonstrated that the concepts of centralized processing and control are viable means of improving resources utilization. The Mark IVA DSN, with less equipment per antenna and smaller staff, is providing a cruise mode telemetry functional availability of 98% which exceeds the requirement of 96% and compares well with the 99% experienced in the Mark III DSN configuration.

The above availability was experienced with software which has not significantly changed since November, 1985. Presently, a major software upgrade package is being delivered. It incorporates many anomaly corrections which will eliminate most of the problems which cause data loss due to antenna pointing errors, and will reduce the stress on operators who must now learn to work around many control anomalies. It is expected that experience gained next year will show functional availability at least as high as in the Mark III era. It also appears that the use of computers in a centralized control configuration will result in even higher performance.

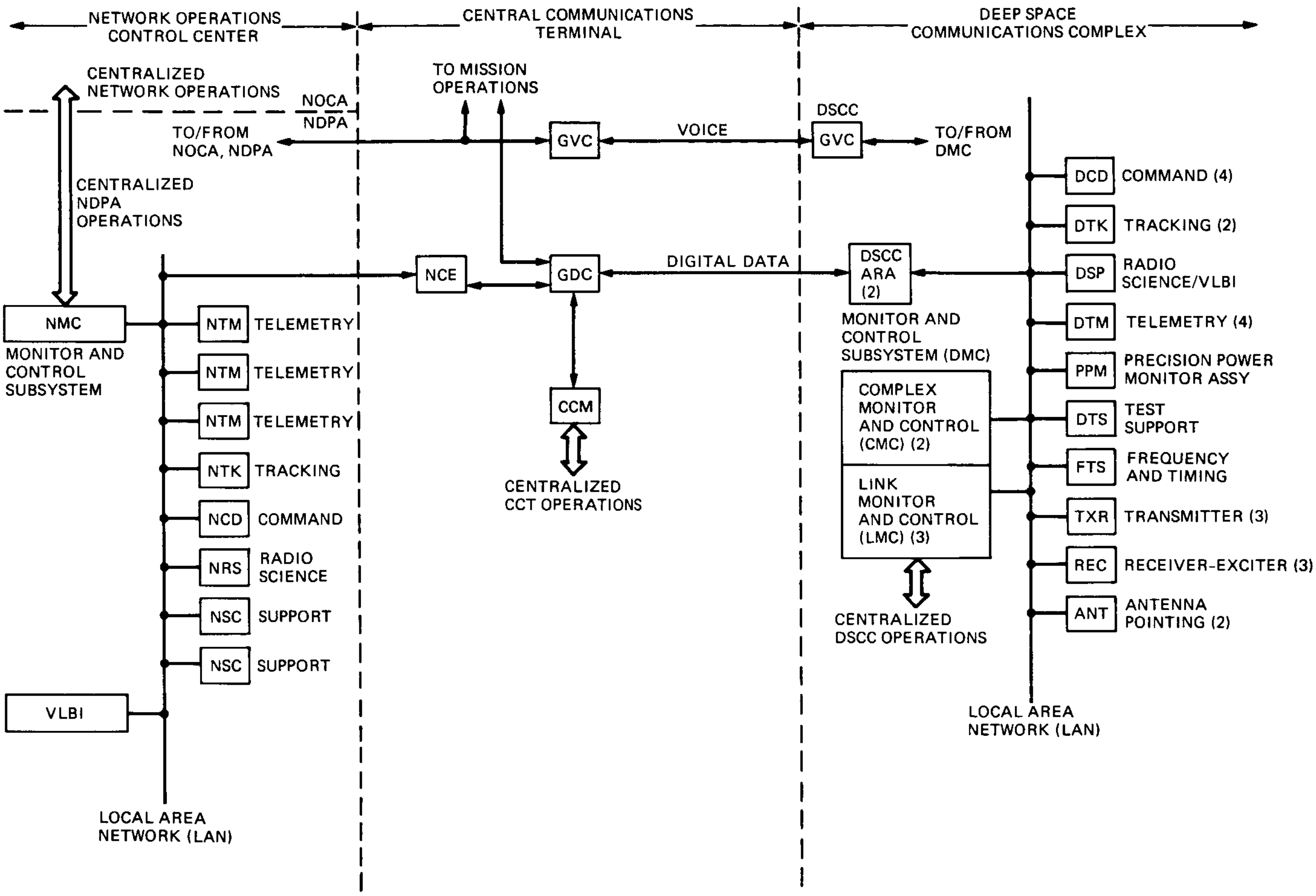

Fig. 1. DSN Monitor and Control System block diagram