Communication Network for Decentralized Remote Tele-Science during the Spacelab Mission IML-2

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ABSTRACT

The ESA communication network for decentralized remote telesccience during the Spacelab mission IML-2, called Interconnection Ground Subnetwork (IGS), provided data, voice conferencing, video distribution/conferencing and high rate data services to 5 remote user centers in Europe. The combination of services allowed the experimenters to interact with their experiments as they would normally do from the Payload Operations Control Center (POCC) at MSFC. In addition, to enhance their science results, they were able to make use of reference facilities and computing resources in their home laboratory, which typically are not available in the POCC. Characteristics of the IML-2 communications implementation were the adaptation to the different user needs based on modular service capabilities of IGS and the cost optimization for the connectivity. This was achieved by using a combination of traditional leased lines, satellite based VSAT connectivity and N-ISDN according to the simulation and mission schedule for each remote site. The central management system of IGS allows to minimize the staffing and the involvement of communications personnel at the remote sites. The successful operation of IGS for IML-2 as a precursor network for the Columbus Orbital Facility (COF) has proven the concept for communications to support the operation of the COF decentralized scenario.

1. INTRODUCTION

For the Columbus Orbital Facility (COF) as part of the International Space Station a distributed European ground segment has been defined. A dedicated network, the Interconnection Ground Subnetwork (IGS) of ESA/ESOC, is in development to provide the necessary communication services to connect the scientists in their remote centers with their experiments in space. In the preparation phases a number of space missions are supported in Columbus-like pre-cursor scenarios to provide proof of concept for the anticipated tele-science/tele-operations infrastructure.

In April 1993 ATLAS-2, a Spacelab mission, was launched for which IGS provided the communications support to perform remote operations of the two European payloads from the Principal Investigators (PI) site in Brussels. These services included data exchange, voice and video conferencing. For the first time an experimenter, who remained in his home base, exercised full control over his experiment aboard Spacelab. After this successful demonstration in July 1994 five European remote user centers participated in a remote experiment operations scenario in the international Spacelab mission IML-2 in which they were able to monitor and adjust their experiments by commands directly from their home bases. This scenario was again based on IGS. The approved remote operations sites in Europe were: CADMOS in Toulouse (France), DUC in Amsterdam (the Netherlands), MARS in Naples (Italy), MUSC in Cologne (Germany), SROC in Brussels (Belgium).

IGS communications uses the Marshall Space Flight Center (MSFC) in Huntsville, Alabama as the relay center to the shuttle and provides the scientists live access to activities aboard the Spacelab in form of video, voice and data transmissions. From MSFC the data are send to ESA/ESOC in Darmstadt by undersea cable, where the IGS central node and the network management is located. From here the data was routed to the European sites of IML-2.

2. COMMUNICATIONS SCENARIO FOR IML-2

The communications scenario for IML-2 is depicted in figure 1. Communications from the Spacelab to MSFC was carried by the NASA Tracking and Data Relay Satellite System (TDRSS) via the White Sands based ground terminal. At the Huntsville Operations Support Center (HOSC), one of the MSFC facilities, ESA has established an IGS Relay which represents the network relay for Spacelab communications and mission operations to Europe.

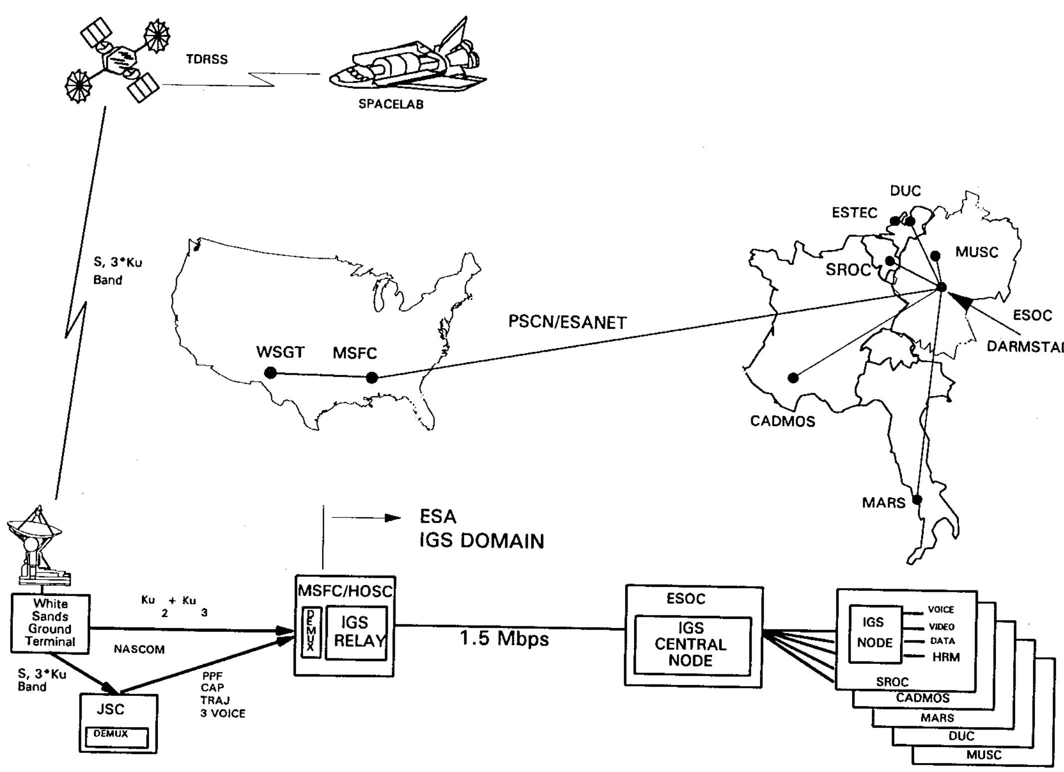


Figure 1 IGS communications scenario for IML-2

For cost reasons in this precursor demonstration the available resources of the general purpose networks of NASA (PSCN) and ESA (ESANET) were chosen as carrier providers for the trans-Atlantic link. At ESOC the complementary IGS central node terminated this 'trunk' and provided the connectivity of the integrated services system for voice, video and data services to the remote sites in Europe. At all remote sites IGS nodes were installed rendering the end-to-end network management capabilities which are required for the reliable operation of networks of this complexity.

For IML-2 the implementation of the **voice** system had to be based on the extension of the NASA Huntsville Voice Data System (HVoDS) with its proprietary formats and signaling. The remote sites can access up to 32 voice loops at the same time.

The analog **video** signals (NTSC at NASA and PAL at the European sites) are digitized and compressed to 384 kbps. Besides simultaneous distribution of on-board video to multiple sites a digital video multipoint control unit at ESOC provides the capability to support any video conferencing configuration between the remote sites, ESOC and NASA.

The IGS frame relay network provides the connectivity for **data** exchange between the workstations which are connected to the LANs at the different sites. This includes the HOSC LAN from where data bases and planning data can be accessed. Since the latter also is interconnected via several other networks including TDRSS with the on-board LAN of Spacelab, the European remote operators were able to directly communicate with their experiment in space, i.e. to send commands and to receive 'low rate science data'.

For the distribution of experiment **high rate data** which were multiplexed aboard Spacelab, IGS provided a special communication service as detailed in paragraph 3.2.

Since the IGS **network management system** at ESOC provides the capability to remotely monitor and control all remote IGS nodes, no communications expertise is required at the remote sites and maintenance interventions could be reduced to a minimum. These are conducted on request and under remote guidance from the communications operations team (IGS Control) at ESOC. The complement team of IGS Control on NASA side is HOSC Comm Control.

Since a low cost approach had to be taken for the remote operations support of the IML-2 mission no backup systems or redundant communication links were foreseen. A reduced prime investigator team for each center was present at MSFC to take over experiment operations in case of a communications failure.

2.1 Implementation Phases

Four major tests preceded the mission: CPS-1, CPS-2, JIS-1 and JIS-2. The last test defined the configuration freeze for the mission. Since only limited capabilities for the remote operations support during some of these tests were required the connectivity cost was optimized according to the actual needs. Three major technologies were used to achieve this:

1. Leased lines with initially lower data rates which were later increased to the bandwidth as required for the mission,
2. Satellite based connectivity with mobile ground stations (VSAT) that provided on-demand establishment of links with fixed data rate,
3. On-demand N-ISDN connectivity using inverse multiplexing techniques in order to combine multiple B-channels to higher aggregates as a substitute for leased lines.

The commonality of all of these types of connectivity is that they interface to the switching system via framed E1 or T1 interfaces, which is a software configurable interface to allow data rates between 64 kbps and 1936 kbps in increments of 64 kbps.
For cost saving reasons the initial bandwidth requirements were reduced or in other cases on-demand connectivities were requested which in later phases were replaced by leased lines. Figure 2 provides an overview of the implementation phases.

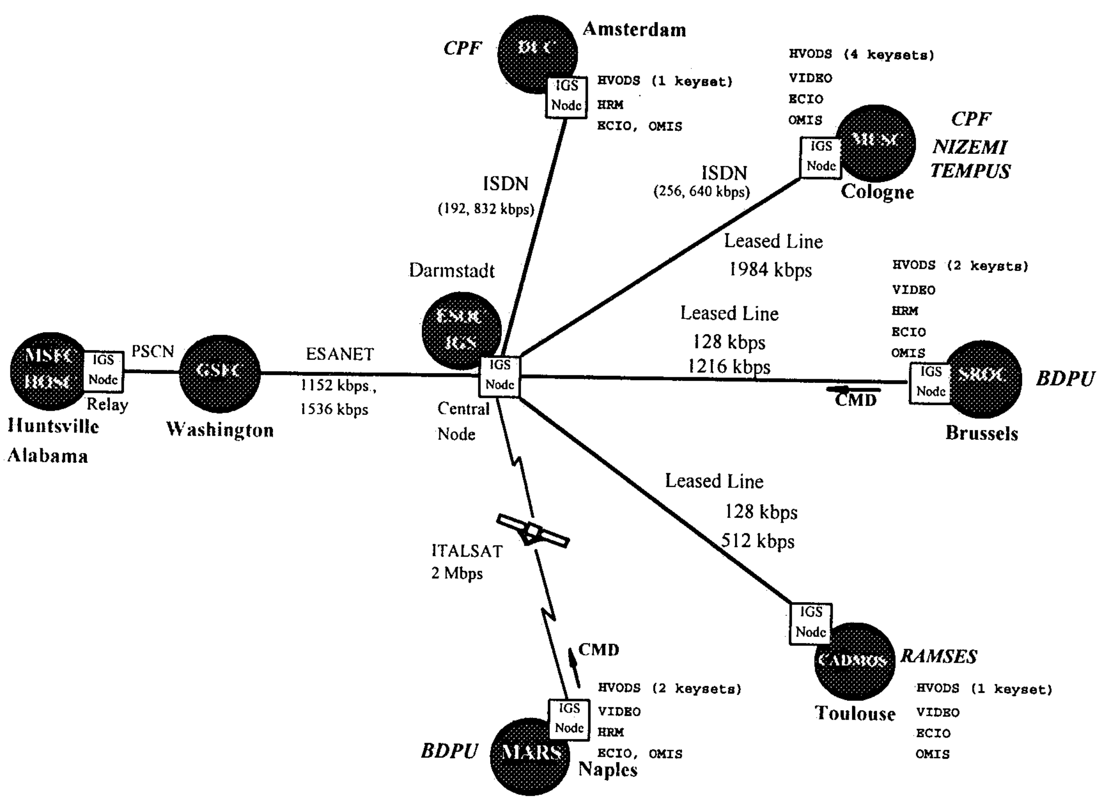


Figure 2 Communication links and implementation phases

3. COMMUNICATION SERVICES

The communication services provided by IGS for IML-2 were derived from the remote operations requirements of each site which are listed below:

1. Low rate housekeeping telemetry reception (ECIO)
2. Low rate experiment telemetry reception (ECIO)
3. High rate experiment telemetry reception of different data rates (HRM)
4. Fixed telecommand sending
5. Variable telecommand sending
6. Access to operations and management information system (OMIS)
7. Voice conferencing
8. Video reception of science video from the experiments aboard Spacelab
9. Video reception of NASA Select to follow the launch and other activities
10. Video conferencing for the science operations planning group (SOPG) meetings

These remote operation requirements resulted in the following IGS services:

1. Data services over IP and DECnet encapsulated in frame relay for 1, 2, 4, 5, 6
2. High Rate Mux Service over switched circuits for requirement 3
3. Voice conferencing service over switched circuits for requirement 7
4. Video distribution and conferencing service for requirements 8, 9, 10
5. A remote management access service over X.25.

These IGS services were supported by an integrated switching system that allows to combine circuit and packet traffic, i.e. frame relay and X.25.
The following subchapters describe the IGS services highlighting the management domains.

3.1 Data Services

The IP and DECnet data services are realized by a multi-protocol router network over a frame relay service provided by the integrated switching system. The management domains are depicted in figure 3. The routers are managed by IGS Control. The end systems connected to the various LANs are managed by their users.

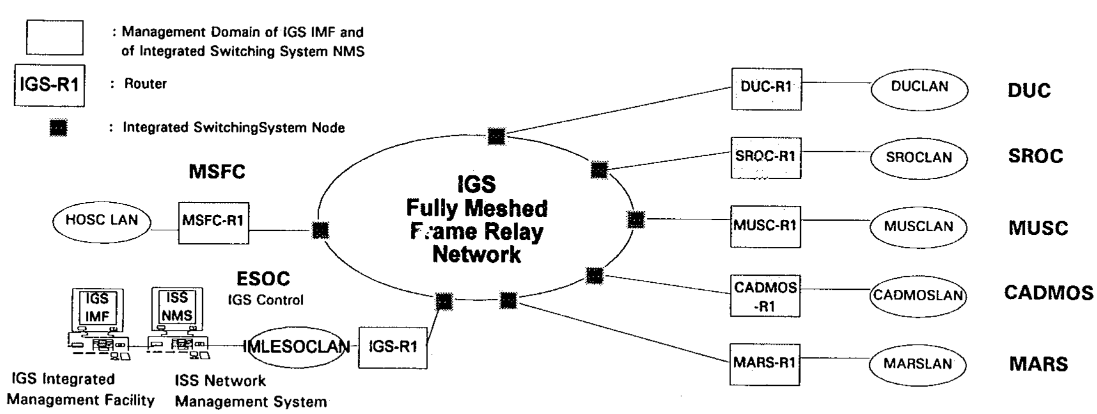


Figure 3 Data Services

3.2 High Rate Mux Service

The high rate mux service is realized by special rate adapters that convert the "odd" data rates of 307.2 and 400 kbps to multiples of 64 kbps that can then be routed as circuits through the integrated switching system.

Figure 4 depicts the management domains. IGS Control provides the switching of the circuit through the switches to the final destination. The rate adapters are managed by HOSC Comm Control.

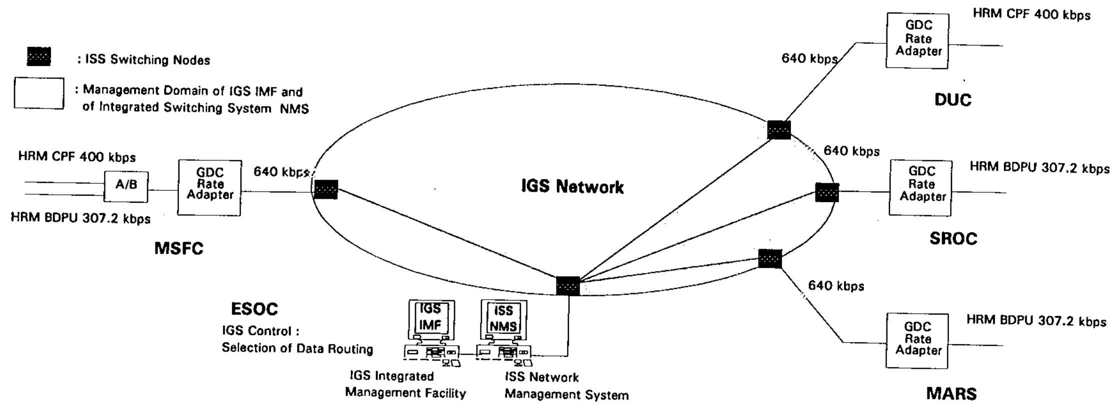


Figure 4 High Rate Mux Service

3.3 Voice Conferencing Service

The voice conferencing service is realized by special dual trunk adapters (DTA) and dual phone adapters (DPA) of the NASA HVoDS system. DTA and DPA pairs are connected by circuits through the integrated switching system.

Figure 5 shows the management domains. The HVoDS DTAs, DPAs and attached keysets are managed by HOSC Comm Control. IGS Control ensures the routing of the circuits through the switches.

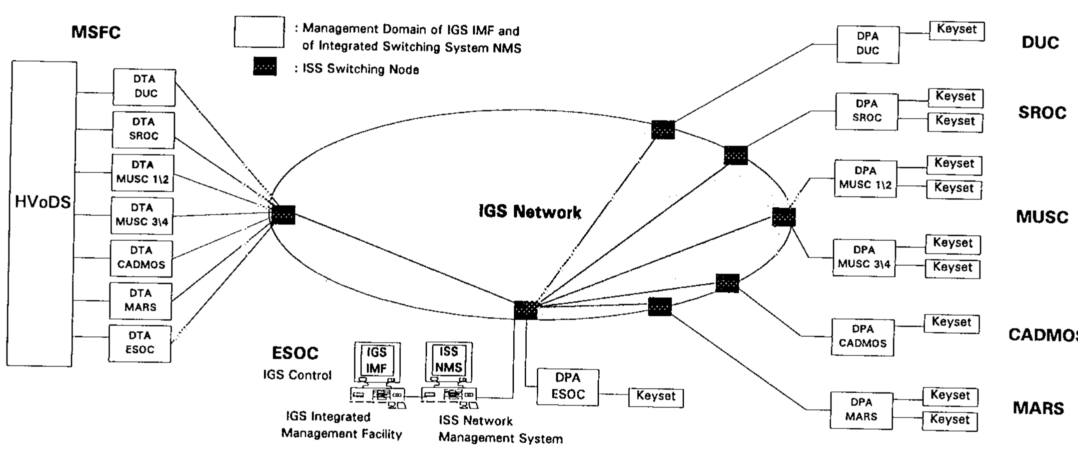


Figure 5 Voice Conferencing Service

3.4 Video Distribution and Conferencing Service

The video distribution and conferencing service is based on video codecs performing H.261 coding and a digital video multipoint control unit. The digitized video is routed as circuits through the main switching system. Figure 6 shows the management domains. The switching of the video streams is conducted from IGS control. The video input from NASA's Huntsville Video Data System (HViDS) is managed by HOSC Comm Control.

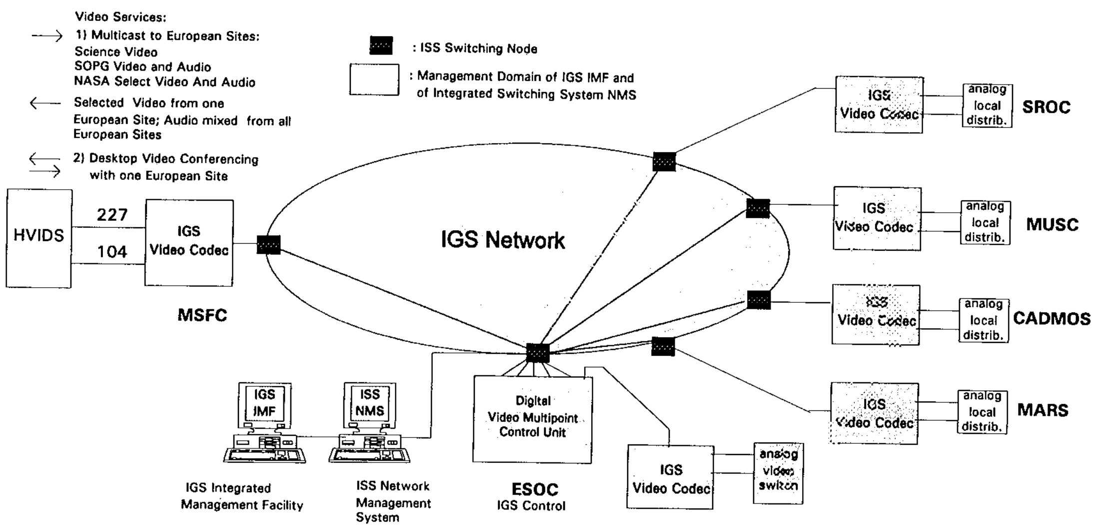


Figure 6 Video Distribution and Conferencing Service

3.5 Remote Management Access Service

The remote management access service is realized over a X.25 service provided by the integrated switching system network connecting packet assemblers/disassemblers (PADs) The management domains are depicted in figure 7. The PADs are managed as part of the main switching system.

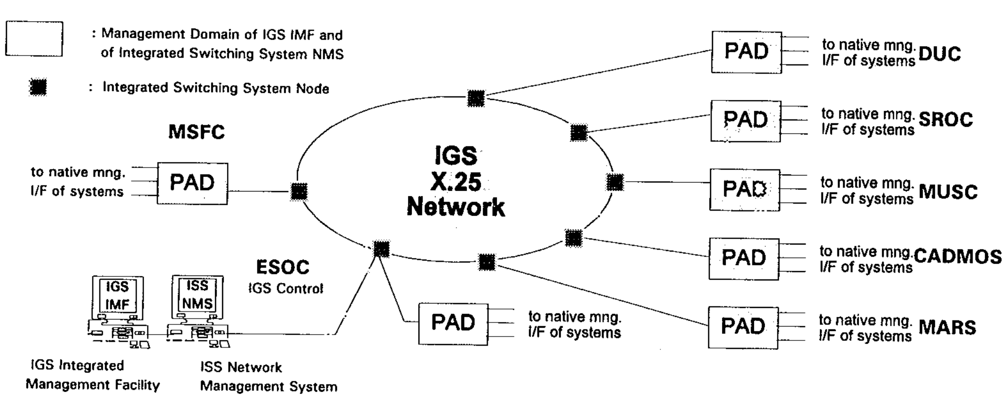


Figure 7 Remote Management Access Service

4. NETWORK MANAGEMENT

The integration of the communication services has been accomplished in two ways: first, at level of transfer, in the sense that the different packet and circuit services are multiplexed together over the link resources and routed through the same integrated switching nodes; second, at the level of network management, because all communications services and the systems which provide them are managed by the same centralized management platforms.

Two management platforms are used: the integrated switching system Network Management System (NMS), and the IGS Integrated Management Facility (IMF). The integrated switching system NMS is the proprietary management system of the core switching nodes on which the network is based. The IGS IMF is a management platform based on an expert-system, which was customized for IML-2 to integrate the management of the heterogeneous subsystems used in the IGS in a single network management system.

The integrated switching system NMS covers all areas of network management for the switching nodes and bases itself on a distributed S/W architecture, thus allowing basic processing of the management information already in the nodes, limiting the traffic on the network trunks to 3-4 kbps of packet bandwidth. Information is displayed on a window-based MMI and colors are used for status indication.

The management domain of the IGS IMF includes the video codecs, the digital video multipoint control unit, and the ISDN inverse multiplexers. These systems do not offer a standard management protocol and are accessed remotely through their native control interfaces.

Knowledge bases in the IMF have been defined for those systems, based on experience gained and with emphasis on the specific use for IML-2. The IMF collects events from all managed systems, including the switching nodes, and evaluates them in a reasoning process, showing correlation between network problems, thus representing a tool to ease problem solutions. Sequences of multiple commands and timed actions are realized as single operations to simplify operator activities. Routers are also managed by the IMF through standard SNMP protocol.

The key aspect of the management architecture that has been described is the centralization of the IGS operations, both for routine and trouble shooting operations.

During routine operations considerable in-service monitoring capabilities allow to exercise constant performance evaluation of the link resources and the services provided, in order to timely react in case degradations are observed.

Trouble shooting or out-of-services network management operations are also conducted in a centralized manner. Complete reconfiguration of faulty systems can be conducted from ESOC, provided that a communication link e.g. a dial-up back-up link with the remote site exists. Loop-backs can be initiated from ESOC in various points of the network for fault isolation. Transmission of test frames and subsequent checking can be also performed from any node

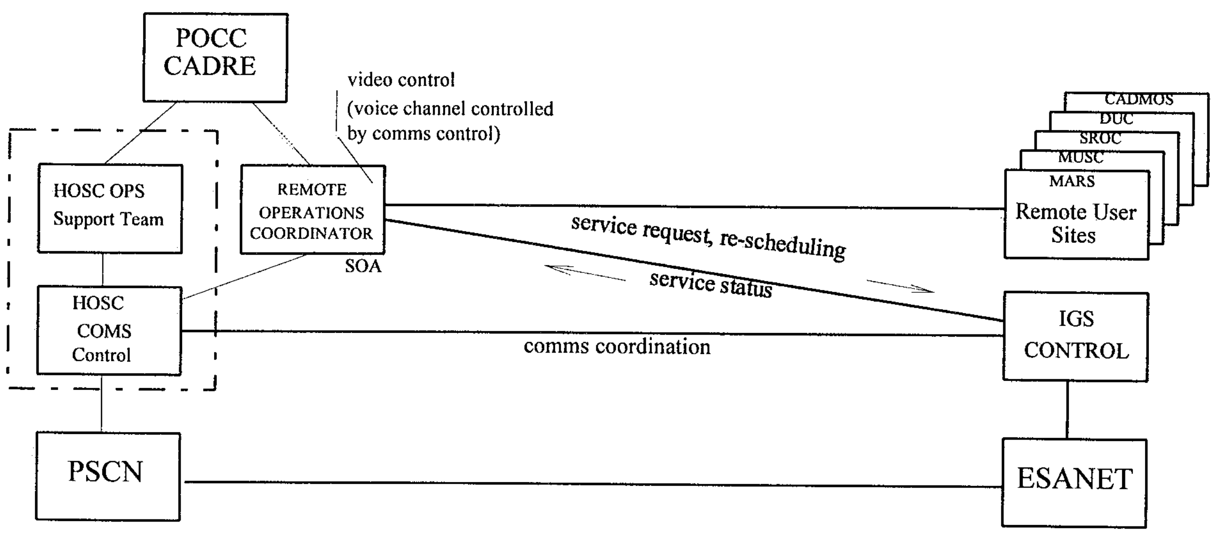
location, eliminating the need and the complications of installing test equipment at the remote sites to trace down difficult problems.
Support at the remote sites is required in principle only for hardware replacement.

5. OPERATIONAL ASPECTS

The timeline defining the activation of experiment aboard of Spacelab and the duration was scheduled well in advance of the IML-2 mission. From this overall timeline the remote operations timeline was derived which in principle represents the scheduled communication service requirements for the operation of IGS. The planned operational activities were

- switching different high rate science data to either DUC, SROC or MARS,
- configuring the ISDN link to DUC into low- or high-data rate mode,
- distribution of NASA select video to the remote user sites,
- configuration of video conferences on request.

Unplanned on-board experiment or resource failures require real-time changes of the timeline for communications operation.



SOA Science Operations Area
REMOPS Remote Operations Coordination

Figure 8 Nominal communications operation

Figure 8 describes the nominal communications operation scenario for IML-2. The IGS operations team (IGS Control) monitored and configured the network by means of the integrated network management system as described above. IGS Control was in permanent contact with the remote operations coordinator who resided during the mission in the science operations area at MSFC via the voice conferencing service. The remote operations coordinator issued requests to IGS Control to perform service changes and received reports on the service status. Some service changes required the support of the HOSC Comm Control, e.g. provision of Spacelab high rate data flow to the IGS Relay at MSFC. For this and similar reasons IGS Control remained in permanent contact with its MSFC complement.

IGS Control permanently monitors the performance of all IGS resources and services and informs the remote operations coordinator on any identified or potential problem. Interfaces to the trunk providing networks PSCN and ESANET are activated only in case carrier problems are identified. Trouble shooting and failure close-out require a close cooperation between the above identified operational positions.

CONCLUSIONS

The successful operation of IGS for IML-2 has demonstrated that decentralized remote telescience can be performed in a reliable and cost effective manner. The modular service capability of the IGS network allows easy adaptation to different user needs. The minimization of the connectivity cost, which is the major cost driver for remote telescience, was achieved by phased implementations and employing the optimum connectivity techniques. The approach of central management of IGS has proven to be a big advantage allowing to minimize staffing and the required communications expertise in the remote sites.

IGS today includes state-of-the art technologies. The strategy which is consequently followed will ensure the direct migration capabilities into the future connectivity techniques e.g. B-ISDN whenever these services demonstrate to be more cost effective.

Subsequent missions which will reuse the proven capabilities of IGS are the Spacelab ATLAS-3 mission October 1994 and other follow-on missions. Also for EUROMIR 95 a scenario based on the available resources of IGS is investigated.

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