Multimedia Services for Interactive Space-Mission Telescience

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ESA is presently preparing the installation of a ground communications infrastructure to support telescience in the scope of the International Space Station (ISS) and the Columbus Orbital Facility (COF), representing the European contribution. Telescience – or remote science operations – is the remote operation of scientific payloads onboard space platforms. The provision of remote operations capabilities for an experiment platform or laboratory in space imposes high safety, reliability and security requirements on the supporting communications system. These requirements are met by the Interconnection Ground Subnetwork (IGS), an ESA-provided autonomous Intranet with gateways to the secure networks of other space agencies. The main objective is to provide scientists with a 'virtual presence' at the experiment workplace in space.

This article focuses on new technologies, which enable and license scientists with limited requirements (e.g. for data availability and access reliability) to operate an experiment in space at minimum communications costs. Additionally, the proposed architectural concept uncovers an access to real-time space events for everyone on the World Wide Web (WWW), which is a significant public relations amplifier. The article describes how multimedia technologies could, already now, support tele-operations of experiments in space and reports on the results of a study in this field conducted by ESA along with an industrial team. An outlook for future service and application developments is also given.

Multimedia profile for low cost science usage

In recent years, ESOC has supported scientists in preparing for future remote science operations in space in the scope of precursor missions with Spacelab, Spacehab and the Russian space station MIR. An important topic of the lessons learned became the awareness that communications carrier services are very expensive when compared to the cost for an experiment's development and operation. The operational scenarios and the applied technologies have been identified, including activities at ESOC to prepare for future high Quality of Service (QoS) communication implementations*. These services within a secure operational Intranet, are rather expensive and are not directly accessible by users with more modest availability and reliability requirements. To serve also these users, the global Internet provides an attractive low-cost alternative.

A study has been conducted together with an industrial team headed by DASA, and supported by ZARM-Fab, OHB-System, and CeBeNetwork all located in Bremen, Germany. The scope of the study was to investigate recent developments in the area of Internet Protocol (IP)-based technology for integrated multimedia networks and to demonstrate solutions suited to the ESA telescience applications. A prototype implementation on the basis of the ESOC communications testbed supported the demonstration. The results have been extrapolated to provide a vision of a future low-cost telescience scenario.

Global public Internet technology and services owe their widespread acceptance partly to the basically distance-insensitive flat-fee tariffing concept. Thus, the Internet appears as the straightforward low-cost solution to deliver experiment data and video streams, even simultaneously, to a very large user community. The limitations of the current IP technology, protocol suite and implementations are nevertheless not allowing true support of real-time multimedia applications over the global Internet as required for telescience. Currently, only a dedicated operational Intranet with guaranteed line capacities could achieve this, as is implemented in the IGS.

Operational scenario for multimedia-based science users

Figure 1 explains how a typical user workstation will be supported with the ESA-provided communications infrastructure for the ISS scenario, the Interconnection Ground Subnetwork (IGS). The figure shows the experiment and how it will be accommodated

* See 'Validating Future Operational Communications Techniques: The ATM Testbed', ESA Bulletin No. 92, November 1997.

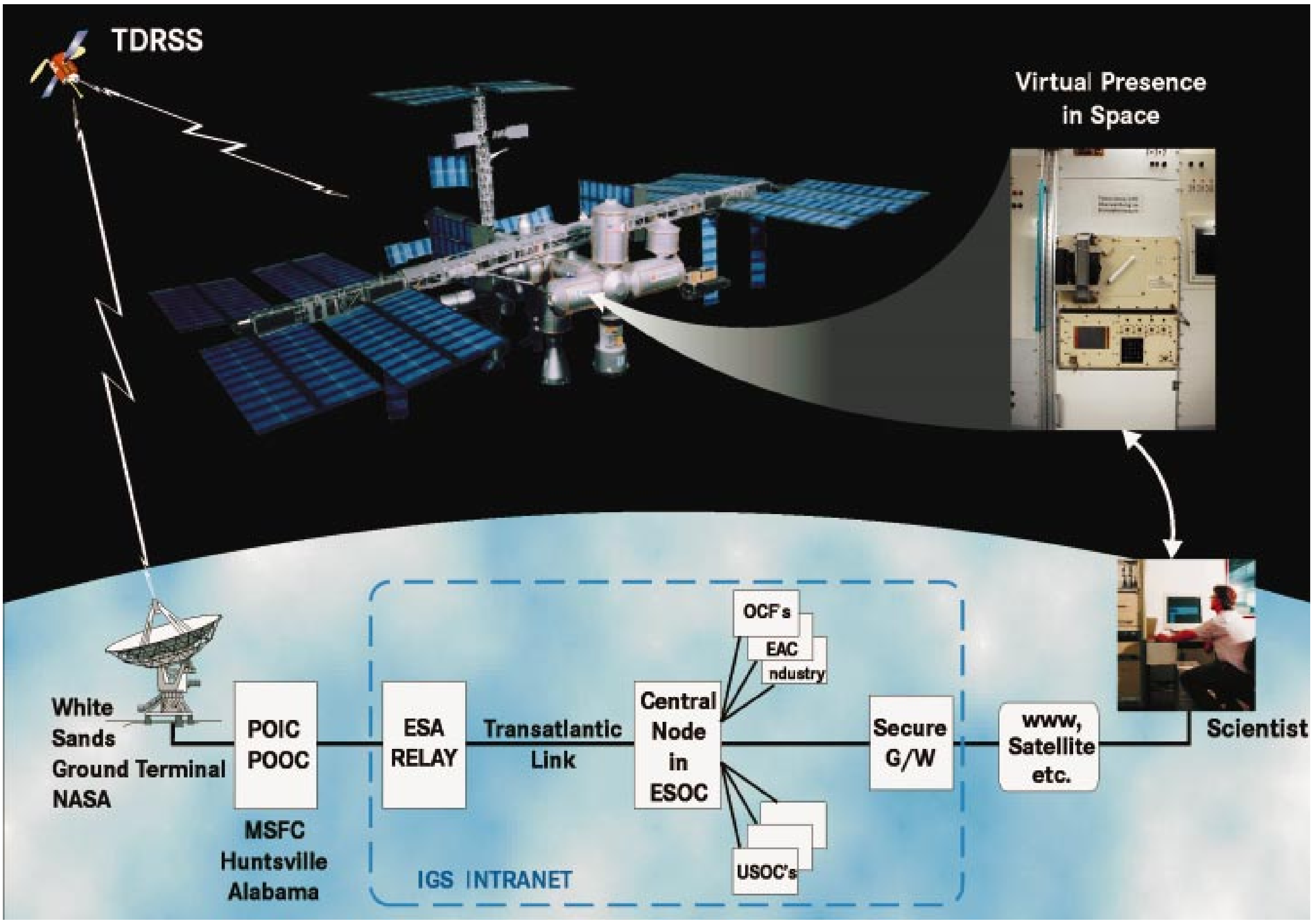


Figure 1. International Space Station scenario with integrated remote-user site

in the COF, the European part of the ISS. Telemetry data, i.e. scientific and housekeeping data and the video streams, will be transferred to ground via a network of geostationary Tracking and Data Relay Satellites (TDRS). The antennas of the NASA ground station in White Sands, New Mexico, will terminate the space-to-ground link. Via high-speed communication lines the data will then be propagated to the Marshall Space Flight Center in Huntsville, Alabama, where the Payload Operations and Integration Centre (POIC) and the Payload Data Service System (PDSS) are located.

Here the European science telemetry data will be transferred to the ESA relay and transported to the IGS central node at ESOC in Darmstadt, Germany, using a highly-reliable Asynchronous Transfer Mode (ATM) service* over a trans-Atlantic link. The IGS central node containing the major operational communications and network management infrastructure is at the centre of a star-like network, interconnecting all involved European operations entities. The entire IGS network is operated and maintained by an industrial control team located at ESOC. The central node services are extended to the global Internet by a secure gateway to protect the secure operational Intranet. Via this gateway, the home-based user can access telemetry data and video streams as standard IP services.

Understanding telescience operations requirements

In developing an experiment to be conducted in space, the dependency of the enhanced scientific return on a real-time interaction capability needs to be evaluated carefully, since the required communications support resources (line cost) can easily become a cost driver when higher data rates need to be supported.

The requirements for the interactive operation of science experiments in space are the following:

– Most users need to monitor their experiment by receiving the telemetry data. They need to display the received housekeeping and experimental data on a monitor, preferably at their home site. These data are numerical values, which provide information on temperatures, velocity, pressures or other measured parameters. In addition, graphical information like pictures or video streams may be of importance to evaluate the experiment's progress. Especially with respect to video streams, the quality requirements

* See 'Validating Future Operational Communications Techniques: The ATM Testbed',ESA Bulletin No. 92, November 1997,

for the communications services are steadily growing. For example, the Critical Point Facility (CPF), during its last mission on EuroMir 94, was supported on the ground by a video service data rate of 384 kbps. The planned Fluid Science Lab (FSL) for the COF with its two high-quality video cameras could even require a video bandwidth of up to 32 Mbps. However, the space-to-ground link resources are limited. In addition, an average of only 4 Mbps (with peak data rates up to 32 Mbps) is allocated to the European complement of the ISS. Also the cost of high-speed data transport on the ground is rather high. Therefore, use of the high-resolution mode for CPF video distribution will be extremely limited.

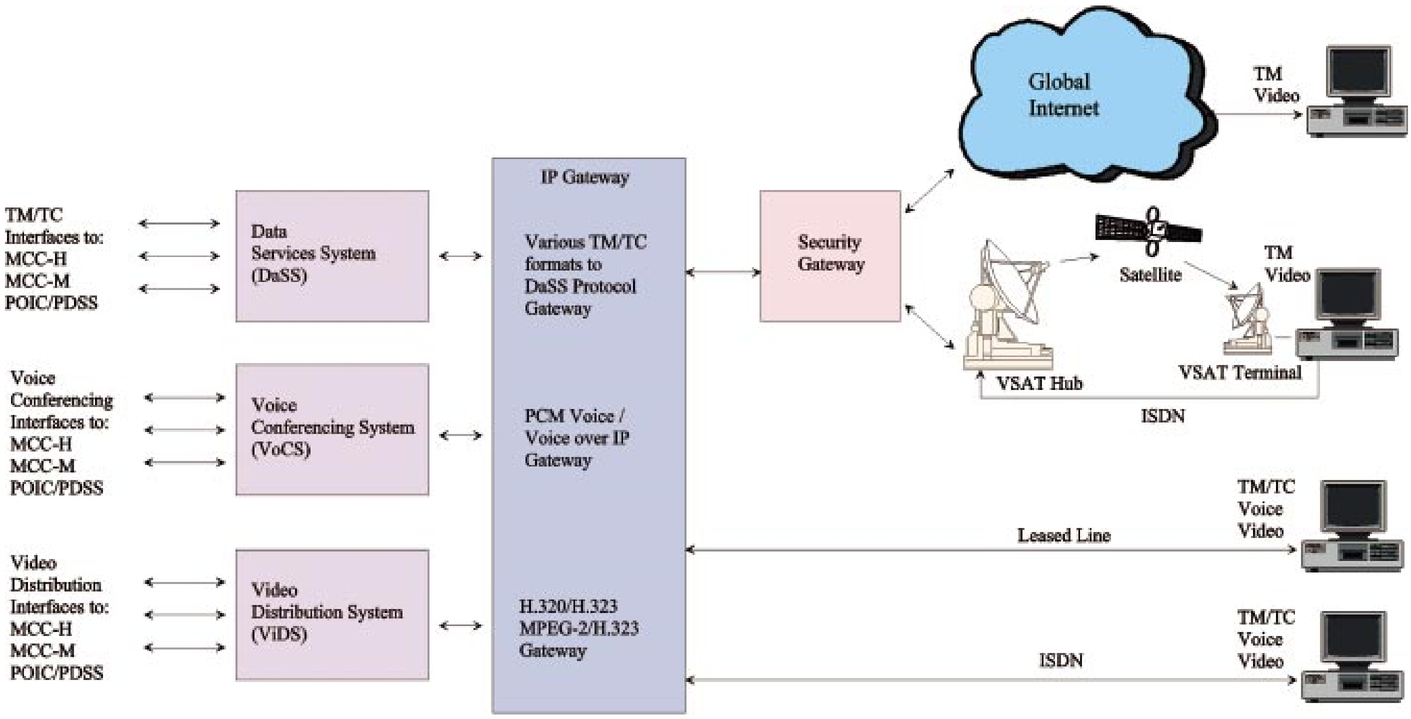
- The second requirement, the online availability of data, is decisive for interactive remote operations. Here a distinction is made between online and offline data distribution. Online implies receiving the data nearly in real time (i.e. within seconds up to a few minutes). Offline means distribution of collected science data with a significant time delay, e.g. overnight.
- To be in the position to react to unexpected experiment events, data must be delivered online, i.e. nearly in real time. The reaction of the experimenter on the ground could be a voice request to a crew member on board the spacecraft or to an experiment facility controller on the ground (requesting the transmission of a telecommand) or directly by a telecommand, sent by the experimenter himself.
- This leads to the third requirement, the experiment control. If the facility design provides this capability, the user should be able to control his experiment by himself. As he is most familiar with his experiment, he should be able to directly issue telecommands.
- As the user has to share the resources of the ISS and COF with other scientists, his experimental work needs close cooperation and coordination with several other operational entities on the ground: the facility responsible (if his experiment is run within a common facility on board the spacecraft), the flight element control centre, which is scheduling, for example, power and possibly the availability of crew time. Therefore, he needs additional communication media to support this coordination. The coordination tools are mainly voice conferencing and video conferencing with other partners and, when available, additional support for cooperative work including application sharing and whiteboards.
- The last requirement results from the considerably longer experiment operations phases within the ISS in comparison to Spacelab and Spacehab missions. In the past, a typical mission had a duration of a couple of days up to two weeks. On the ISS, a mission or increment can be three months or more. Under these extended mission conditions the user wants to stay at home. In the past, the user had to move with most of his ground support equipment to a NASA site to monitor his experiment. Now the user can operate his experiment from his institute, where he has his supporting science staff and all the necessary processing resources available.

All of these requirements need to be considered when designing a remote user environment. In addition, the communication cost must remain reasonable in relation to the overall cost of an experiment. The cheapest and most flexible solution which fulfils all of the above requirements with an acceptable service quality, would be the ultimate answer for the user.

IP gateway to operational services

In order to enable low-cost access at a central European site to the operational communication infrastructure of the ISS, it is first necessary to map all operational services (telemetry, telecommand, voice conferencing and video distribution) to the Internet Protocol (IP), which then allows one to easily map the IP service to the most appropriate and cost effective underlying carrier service. Figure 2 shows the IP Gateway Concept which is part of the IGS Central Node.

The data services for telemetry and telecommand are provided by the IGS Data Services System (DaSS), which interfaces with all partner control centres involved in ISS operations, i.e. the Mission Control Centre Houston (MCC-H), the Mission Control Centre Moscow (MCC-M), the Payload Operations Integration Centre (POIC) and the Payload Data Service System (PDSS). Together with the IP gateway, it accommodates all required TM/TC format conversions to provide a unique simple interface to the users via TCP/IP. Similarly, the interfacing for the voice conferencing services of partner control centres is provided by the IGS Voice Conferencing System (VoCS). An IP gateway function converts the pulse code modulated (PCM) voice signals into Voice over IP, requiring very low bandwidth. In the same manner, the interfacing for the video distribution services of partner control centres is provided by the IGS Video Distribution System (ViDS). An IP gateway function converts the H.320 or MPEG-2 coded video streams into low rate H.323 video signals.



Legend:
TM: Telemetry
TC: Telecommand
MCC-H: Mission Control Center Houston
MCC-M: Mission Control Center Moscow
POIC: Payload Operations Integration Center
PDSS: Payload Data Service System
PCM: Pulse Code Modulation
IP: Internet Protocol
MPEG: Motion Picture Export Group
ISDN: Integrated Services Digital Network
VSAT: Very Small Aperture Terminal

Figure 2. IGS Central Node - IP Gateway Concept

Once all services (data, voice and video) are converted to IP, it is easy to map the IP service to different carrier services depending on the user requirements. Via a security gateway, a multitude of users can be connected to the operational environment via the global Internet. Due to the current unreliable performance of the global Internet, it is envisaged to provide online/offline telemetry and video only. Via a security gateway to a VSAT system service, highly asymmetric and multicast traffic profiles can be supported in which a user community receives much more data than is sent back into the operational environment. This is typical for multi-user offline telemetry distribution for which the VSAT service represents a low-cost solution. Also, via a security gateway, a secure tunnel can be established over the global Internet, which has similar characteristics to a direct link. It is therefore assumed that the full range of operational services, i.e. telemetry, telecommand, voice conferencing and video distribution, is available over this type of setup with, however, fluctuating performance. Via leased lines or ISDN dial-up services, a user can be provided with the full range of operational services with guaranteed performance. ISDN only supports data rates up to 2 Mbps.

In the context of the study, various commercial off-the-shelf products for the IP gateway are being evaluated for the individual services:

1. Online telemetry distribution is available over TCP/IP, i.e. no gateway function is required.
2. Offline telemetry distribution uses the reliable Multicast File Transfer Protocol (MFTP) over IP multicast to transfer data to multiple users over different carrier services at the same time.
3. Voice conferencing is assumed to be partly covered by video conferencing, which always includes an audio channel.
4. Video distribution uses an H.320 to H.323 conversion, which implements the video gateway functionality; for onward distribution to multiple users IP multicast is employed based on the IP/TV and the reflector products.

Internet Service Providers (ISPs)

The global Internet is built by interconnection of Internet Service Provider (ISP) networks. The global Internet, and also private operational Intranets, are based on the current IP version 4 (IPv4), which does not allow bandwidth reservation on an application basis, rather the IP service is provided on a ‘best effort basis’. Over the global Internet, low data rates – up to a few kbps – could be supported for science data transfer. It is, therefore, a good choice for monitoring low-rate telemetry, but it is definitely not adequate for telecommanding, where guaranteed data rates and minimum latency are mandatory. The problem of security and confidentiality of data can be solved by data encryption techniques. Video distribution/ conferencing and especially audio conferencing via the global Internet is also possible. However, the availability of bandwidth is unpredictable with high fluctuations depending on the entire traffic load. Only those tools that can also adapt to degraded modes can cope with these limitations. World-wide investments by terrestrial Telecoms and Internet Service Providers (ISPs) in new access technologies, e.g. Asymmetric Digital Subscriber Line (ADSL),

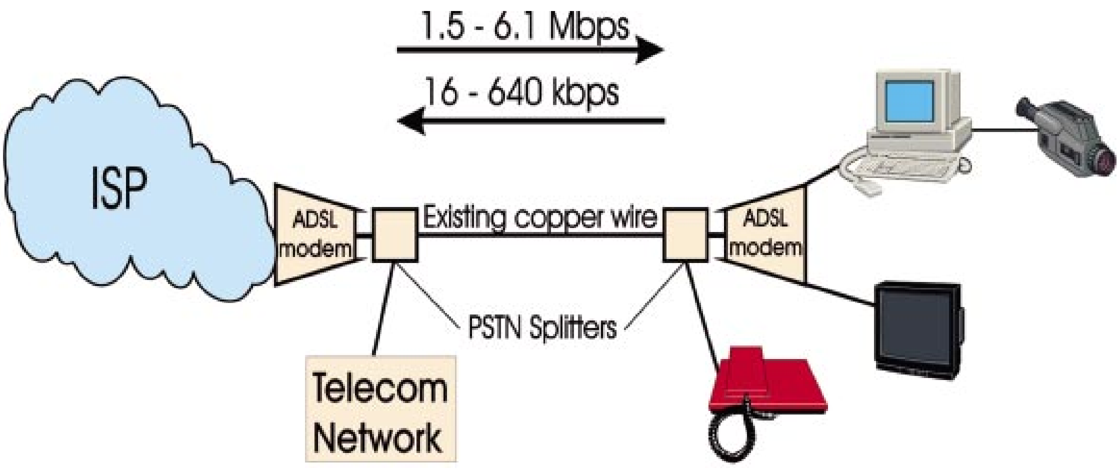


Figure 3. Asymmetric Digital Subscriber Line (ADSL)

and enhancements of their backbone networks with Asynchronous Transfer Mode (ATM) suggest that global Internet performance will increase rapidly in the next years.

ADSL is designed to improve the low bandwidth access connection between the terrestrial ISPs and the service users, which today access the ISP via telephone modem, ISDN or leased lines. The major advantage of ADSL is that it uses the existing copper wire infrastructure of the Public Switched Telephone Network (PSTN) and can operate seamlessly in parallel with the existing telephone service. Figure 3 shows how the user can reach his ISP and telephone provider over the same pair of copper wires (up to 8 km). The ADSL access is highly asymmetric, i.e. between 1.5 and 6.1 Mbps are possible in the ISP-to-user direction, but only 16 to 640 kbps are available in the reverse direction. This asymmetricity is adequate for a typical global Internet user.

Other ISPs do not use terrestrial access technologies but rather satellite-based ones. Figure 4 shows a Very Small Aperture Terminal (VSAT)-based system that can distribute up to 12 Mbps to a multitude of users. The main VSAT Hub (uplink) station is connected via dedicated connectivity to the IGS Central Node IP Gateway from where it receives the data (telemetry, video distribution) to be uplinked. The distribution is via geostationary satellite to the VSAT system users who interface from their PCs via a special PC-card and an outside antenna to the VSAT system. A low-rate return channel via telephone modem is normally provided via a terrestrial ISP through the global Internet to the VSAT provider to allow interactive applications. VSAT-based access technology provides a cost advantage when the same data needs to be multicasted to a large user community.

ISDN and leased lines

Dial-up ISDN lines can easily extend the full range of IGS operational services. Currently, dial-up ISDN lines are the best trade-off between cost effectiveness and secure connectivity, with minimal delay and a guaranteed bandwidth for short periods of time. A cost trade-off between leased lines and ISDN has to be made for each experiment mission profile. ISDN lines can be bundled in increments of 64 kbps to a single data link of up to 2 Mbps, allowing low- and medium-rate telemetry transfer and also telecommanding, due to its guaranteed bandwidth and high security. Additionally, audio and video conferencing is easily supported by this technology.

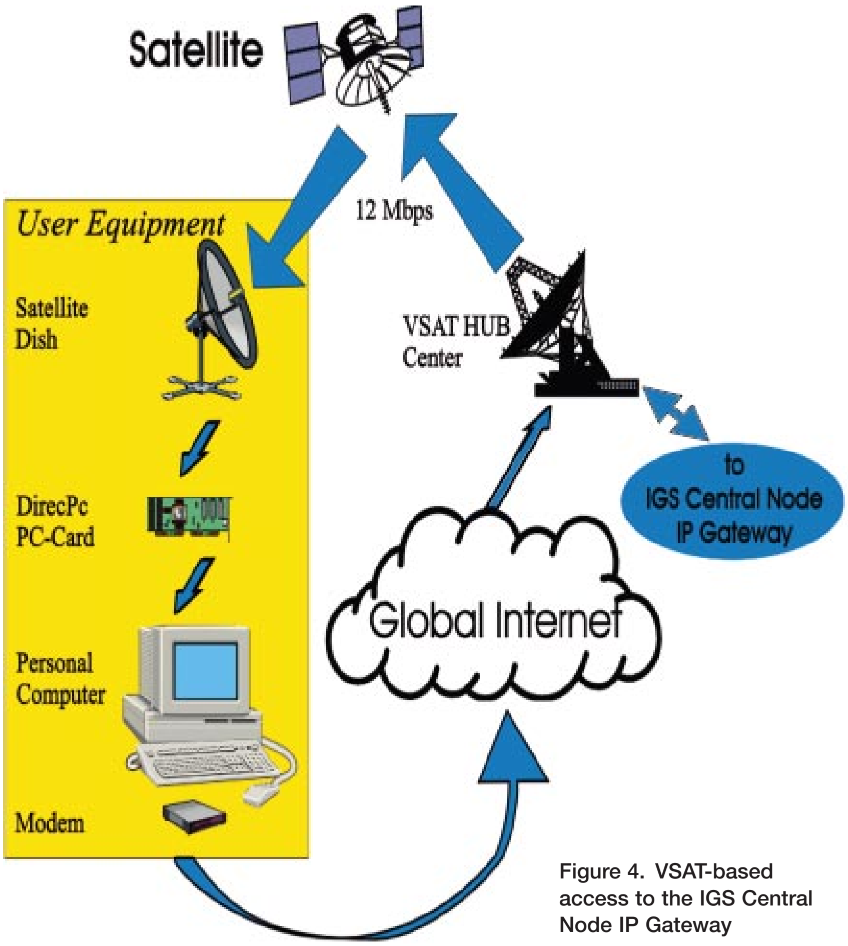


Figure 4. VSAT-based access to the IGS Central Node IP Gateway

IP version 6

The lack of adequate bandwidth for telecommanding is one of the major deficits of IP version 4. New bandwidth reservation schemes known as IP version 6 (IPv6) are being standardised. In the context of the study, the first beta version implementations of IPv6 are being tested. Although it is not expected that the global Internet will quickly move towards IPv6, it is predictable that this technology can be easily implemented in the private IGS Intranet, which would connect users via leased lines and ISDN directly into the operational communication environment. This would allow the telescience user to base himself on standard IP services with guaranteed bandwidth for each application in a low-cost telescience workstation.

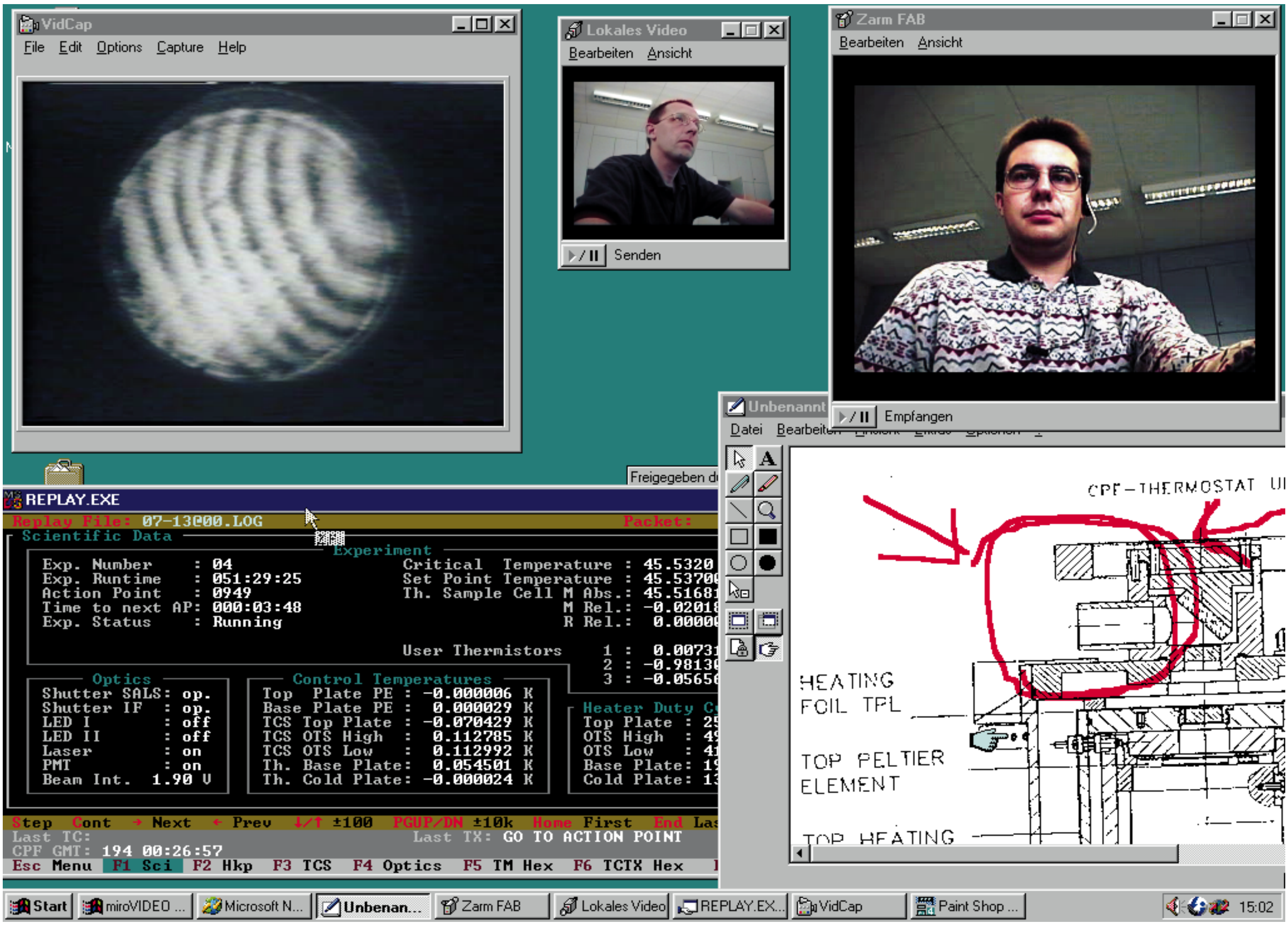
IP multicast

IP multicast is a technique to distribute the same data to multiple users of IP networks by minimising the network load. In the context of the study, this mechanism has been tested over terrestrial IP networks and VSAT-based IP networks. Within the IGS, this mechanism is interesting for online/offline telemetry distribution and video distribution. A reliable Multicast File Transfer operating over the IP multicast network service can implement offline telemetry distribution. Such a scenario will actually be demonstrated and evaluated based on the Multicast File Transfer Protocol, which allows, in particular, a wide variety of data rates between sender and receivers (few kbps to Mbps) in the same multicast tree.

Mapping space science operating requirements to the virtual workplace in space

In the following, an economic implementation of an experimenter workplace is described based on current multimedia technology. It is a demonstration build-up representing the user front-end for an experimenter who is working with the Critical Point Facility (CPF) used within the Bremen Engineering Operation Science (beos) as a demonstration facility. The demonstration is built up exclusively of existing ground S/W of the CPF facility augmented by commercial-off-the-shelf software and hardware integrated in a single PC. Figure 5 depicts how these tools could be combined for low-cost, interactive telescience. All communication tools are based on the Internet Protocol, which is the de-facto standard for data transport, thus providing the necessary

Figure 5. Screen dump of the user terminal demonstration



flexibility with respect to the transport media (carrier service).

The screen shown in Figure 5 accommodates several windows, which provide all the required functionality needed for this demonstration:

- *Monitoring and control*: In the lower left window of the screen, the typical display of a numerically-oriented payload front-end is shown which is a CPF-specific EGSE data display. In the COF scenario, these data will be based on a CCSDS/IP data stream provided by the Data Services System (DaSS). From this display, pre-validated telecommands could also be selected for transmission.
- *Monitoring of video*: The video stream from the on-board experiment facility is part of the down-link video and can be shown on the screen by a multimedia player (upper left window). The video service is provided by the Video Distribution System (ViDS) of the operational communications infrastructure.
- *Coordination*: For operational coordination, several PC tools can provide the necessary functionality. Audio and video conferencing between different partners is possible, and can be integrated with the Voice Conferencing System (VoCS) and Video Distribution System (ViDS), which are part of the ESA-provided operational communications infrastructure. Two parties are engaged in a conference as shown in the upper right part of the display. The smaller window shows a self-view of the participant; the other window presents the image of the counterpart. Below the video windows, a whiteboard has been opened which is being used for discussion of the CPF thermostat unit, and free-hand-drawn pointers and annotations are being used to help in the discussion. Also, any other application located in any of the participating PCs could be shared.
- *At the home site*: Everything the user needs is integrated in one low-cost workstation (PC) which can be located anywhere in the world where sufficient communication services are provided – but preferably in the experimenter's office or laboratory. This represents substantial savings in terms of cost and time (e.g. travel requirements are minimised).

Conclusion

The needs of experimenters for new technologies, services and applications – which demarcate today's multimedia solutions – at substantially reduced communication costs, provided the motivation to investigate alternatives for low-cost, interactive space telescience. These investigations focused on those implementations which are supported by access services to the global Internet since its communications costs are not distance-sensitive. The requirements for operating a spacecraft and experiments call for the proof of high reliability, availability and performance by the supporting communications infrastructure, resulting in significant carrier costs. For the COF scenario, a topology is proposed which provides a secure Internet-based access to the operational communications services.

Within the framework of an industrial study, various products have been evaluated which support data, voice, video and shared application services. The experience gained within the study attests that current services and applications based on the global Internet can provide adequate and inexpensive support for scientists in tele-operating their experiments in space. However, the underlying network resources have to be shared with other public users and the competition for bandwidth can result in severe communication service degradations, which some experiment scenarios may not tolerate. Even so, experimenters with less critical requirements will find Internet-based services the most economic.

The considerable development activities in communications technology and the continuous expansion of global Internet resources should result in significant performance improvements for Web-based services. Presently, major progress is reported in the fields of VSAT-based services, in bandwidth reservation techniques like IPv6, in ADSL modem technology and in the build-up of relevant support infrastructures. It is very likely that even within the initial International Space Station exploitation phase, the performance of the global Internet will grow from the currently low kbps data flow to a more reliable data service (even up to 6 Mbps).

Acknowledgements

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